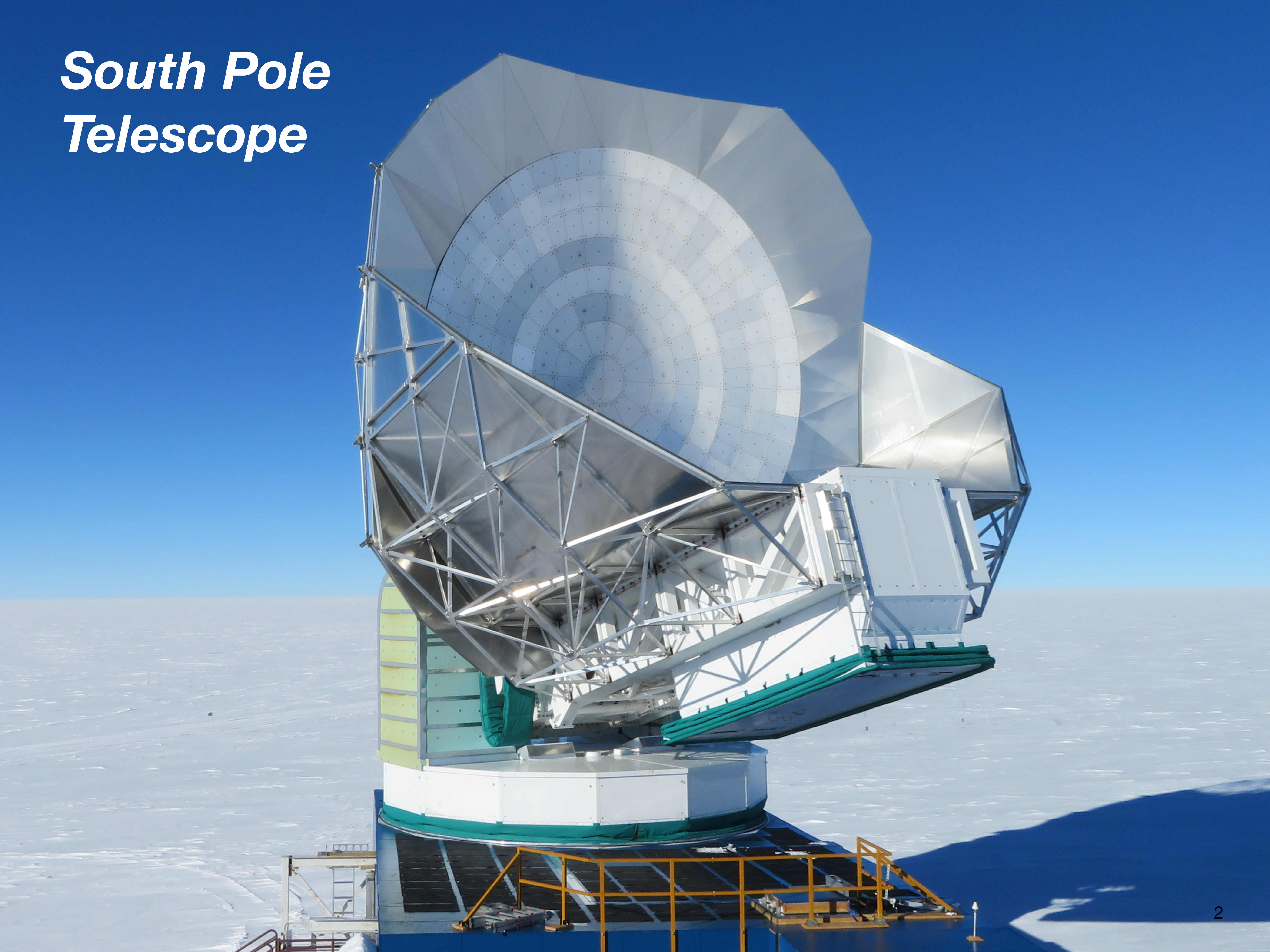
Cosmology at the South Pole

Adam Anderson
CAB Meeting
28 May 2020

South Pole Telescope



Cosmic Timeline

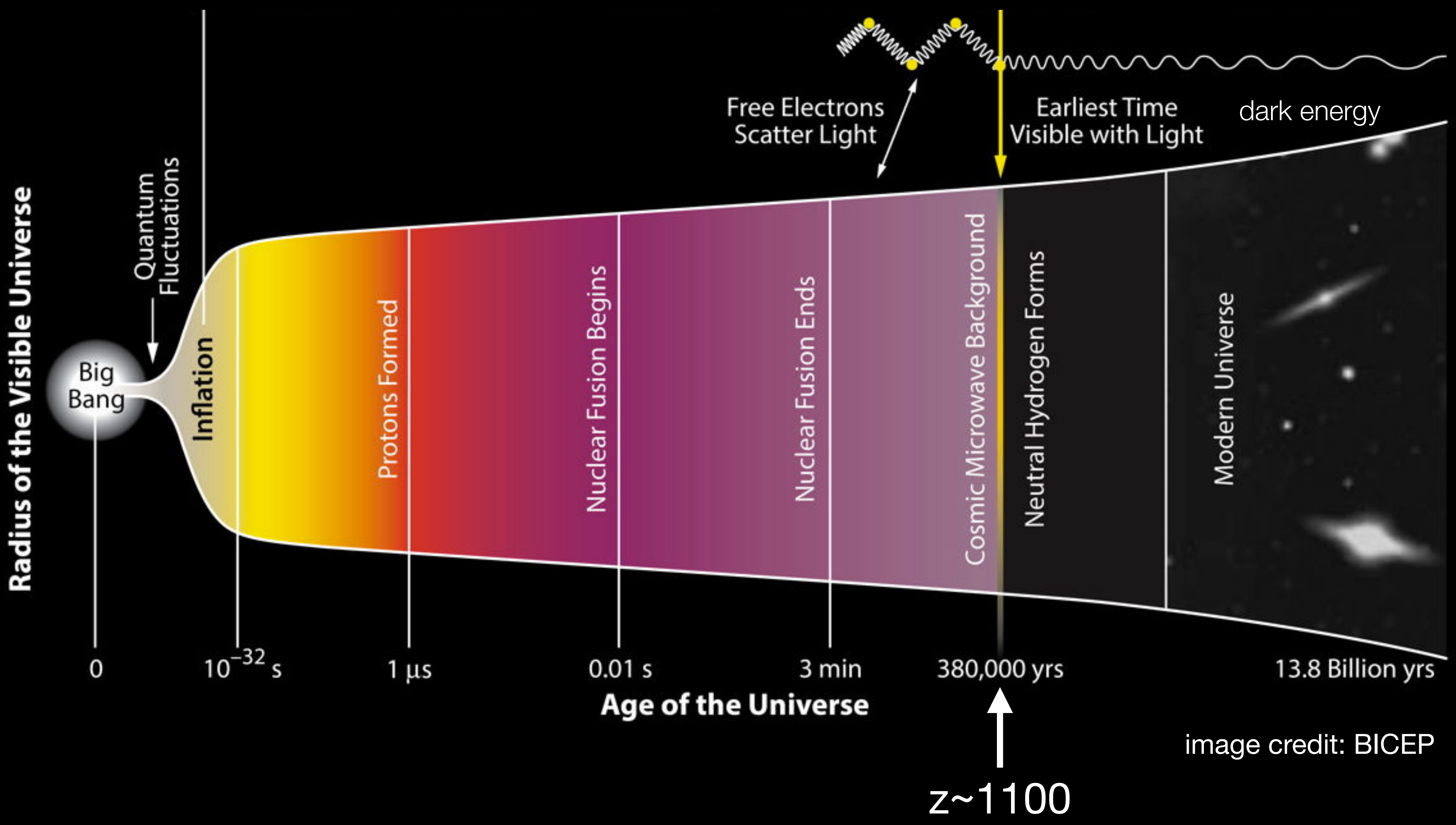


image credit: BICEP

Cosmic Timeline

I. Recombination

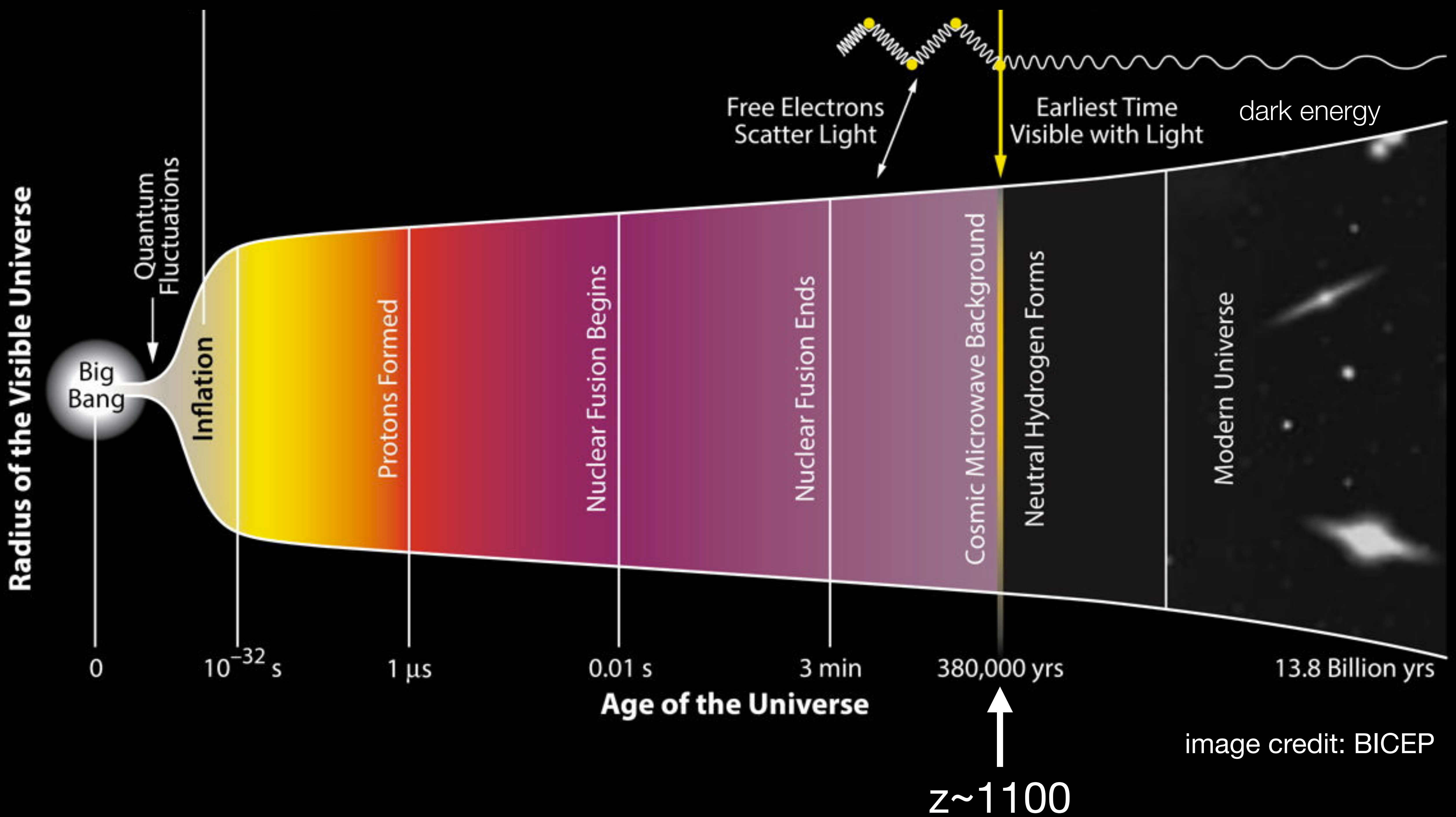
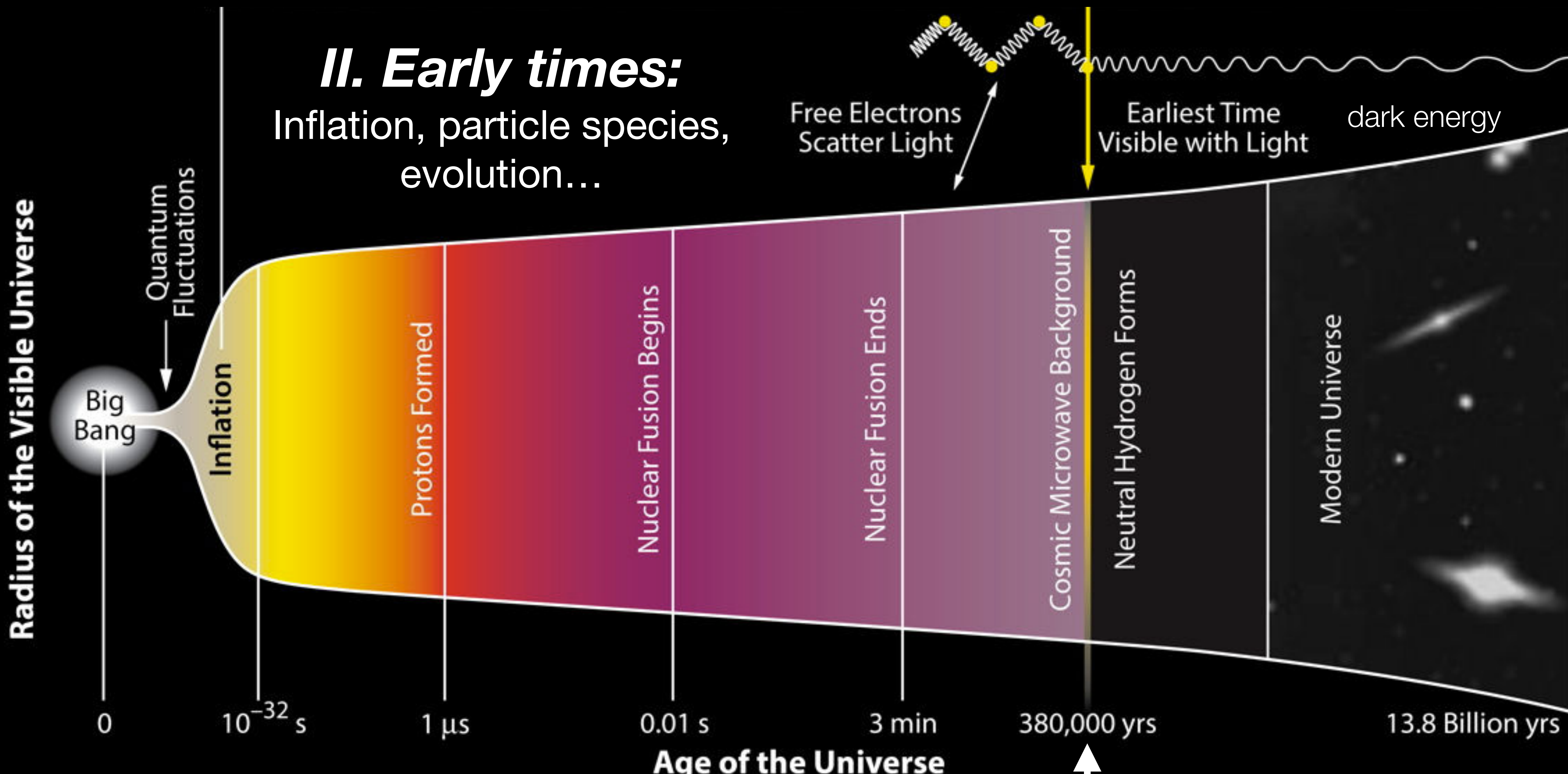


image credit: BICEP

Cosmic Timeline

I. Recombination

II. Early times:
Inflation, particle species, evolution…



z~1100

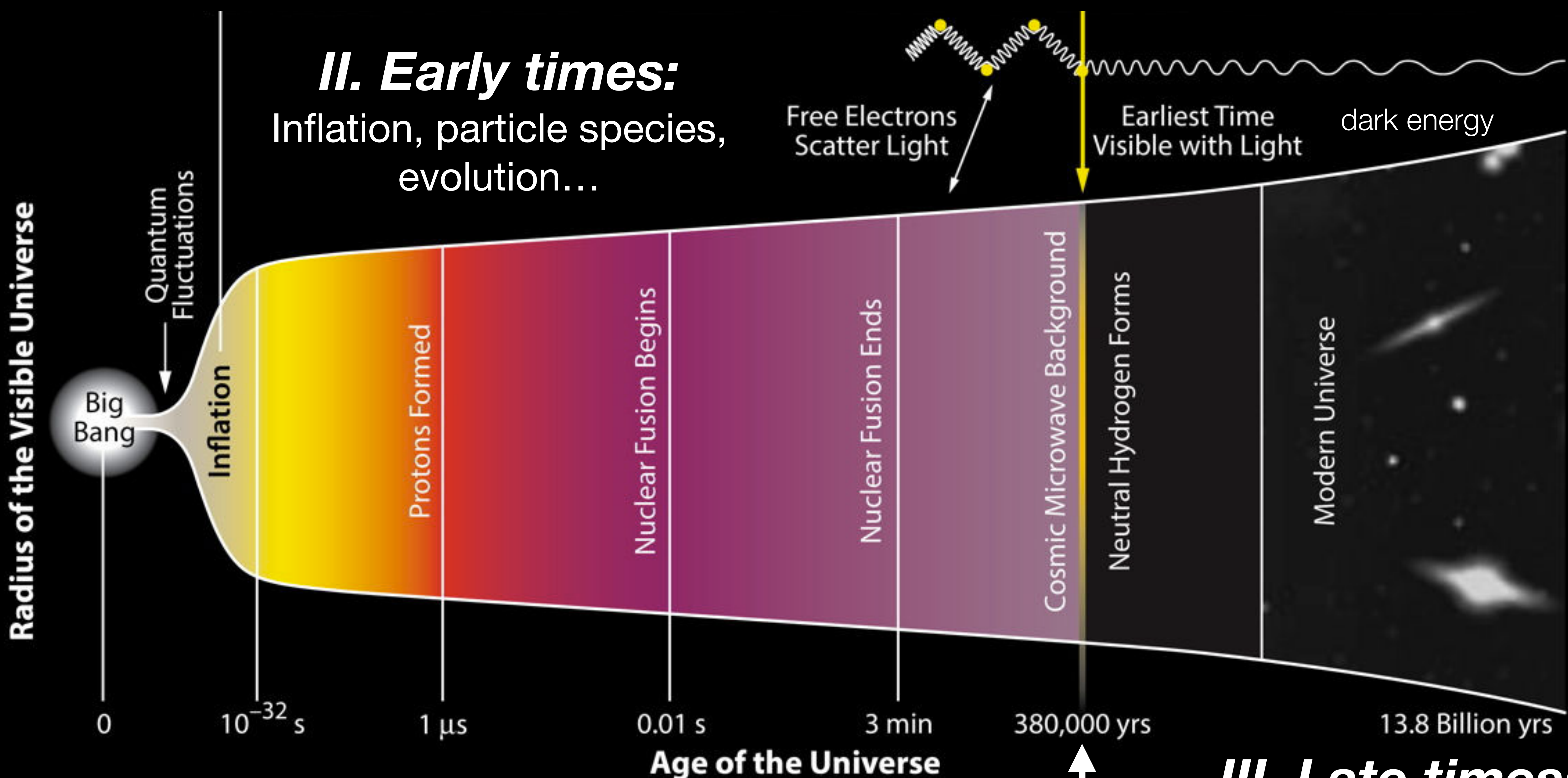
image credit: BICEP

Cosmic Timeline

I. Recombination

II. Early times:

Inflation, particle species, evolution…



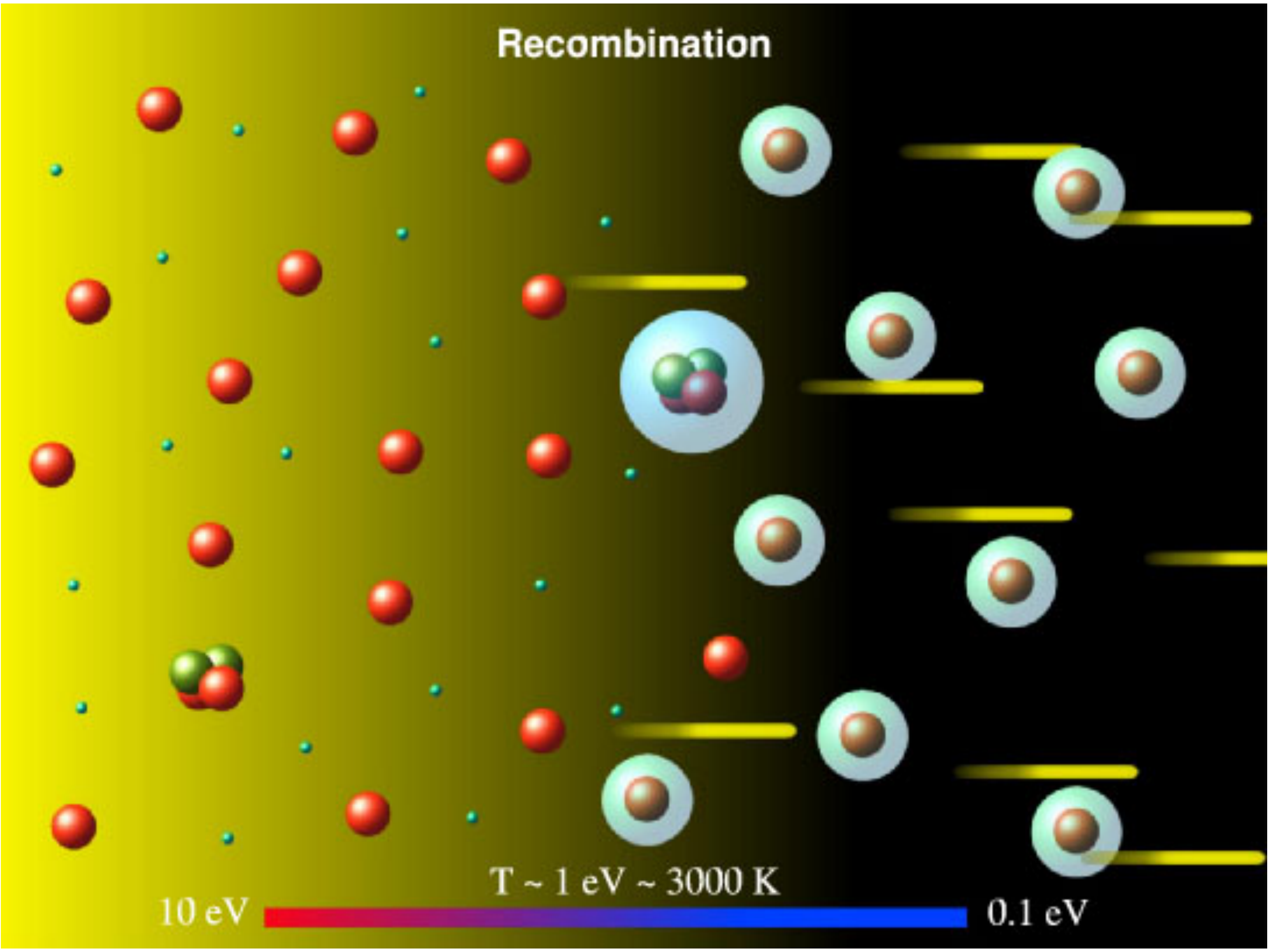
z~1100

III. Late times:

Gravitational lensing, structure formation…

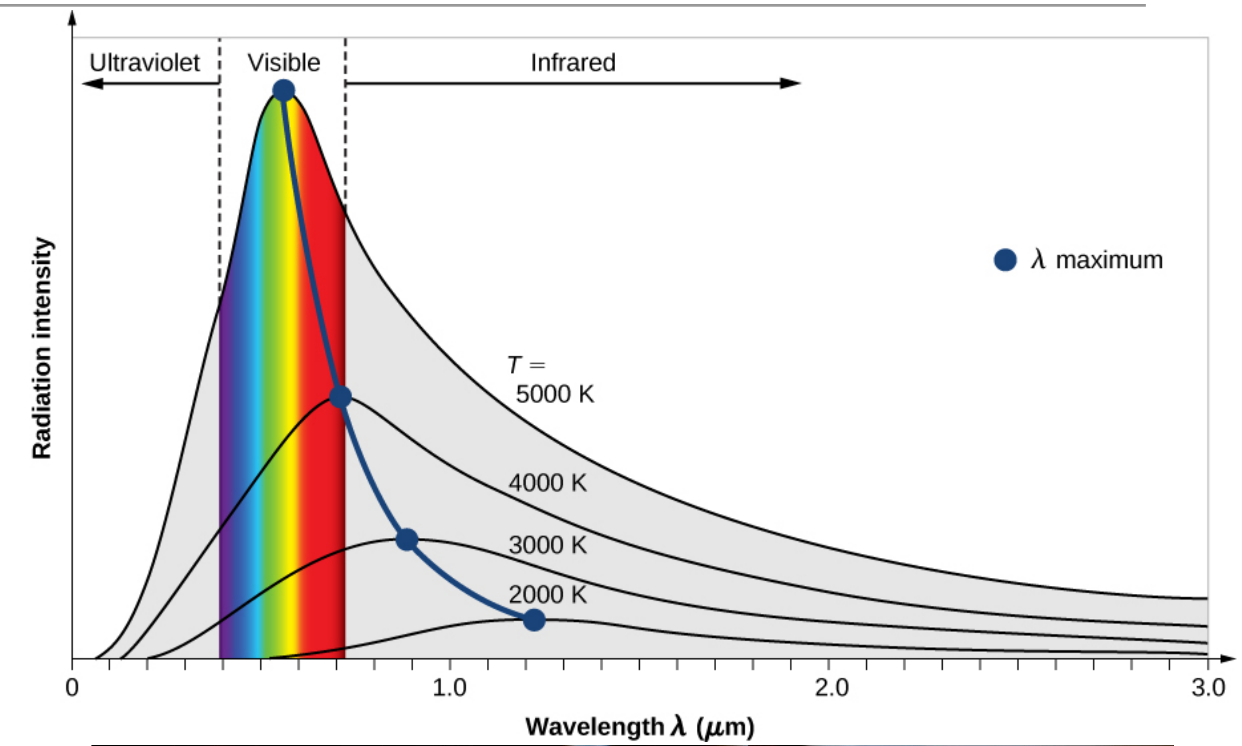
Cosmic Microwave Background

- At early times, nearly all matter is a plasma of free protons, electrons, and photons
- The plasma is ***opaque*** to photons
- As universe expands, it cools, and eventually neutral Hydrogen forms
- Neutral hydrogen is ***transparent*** to photons

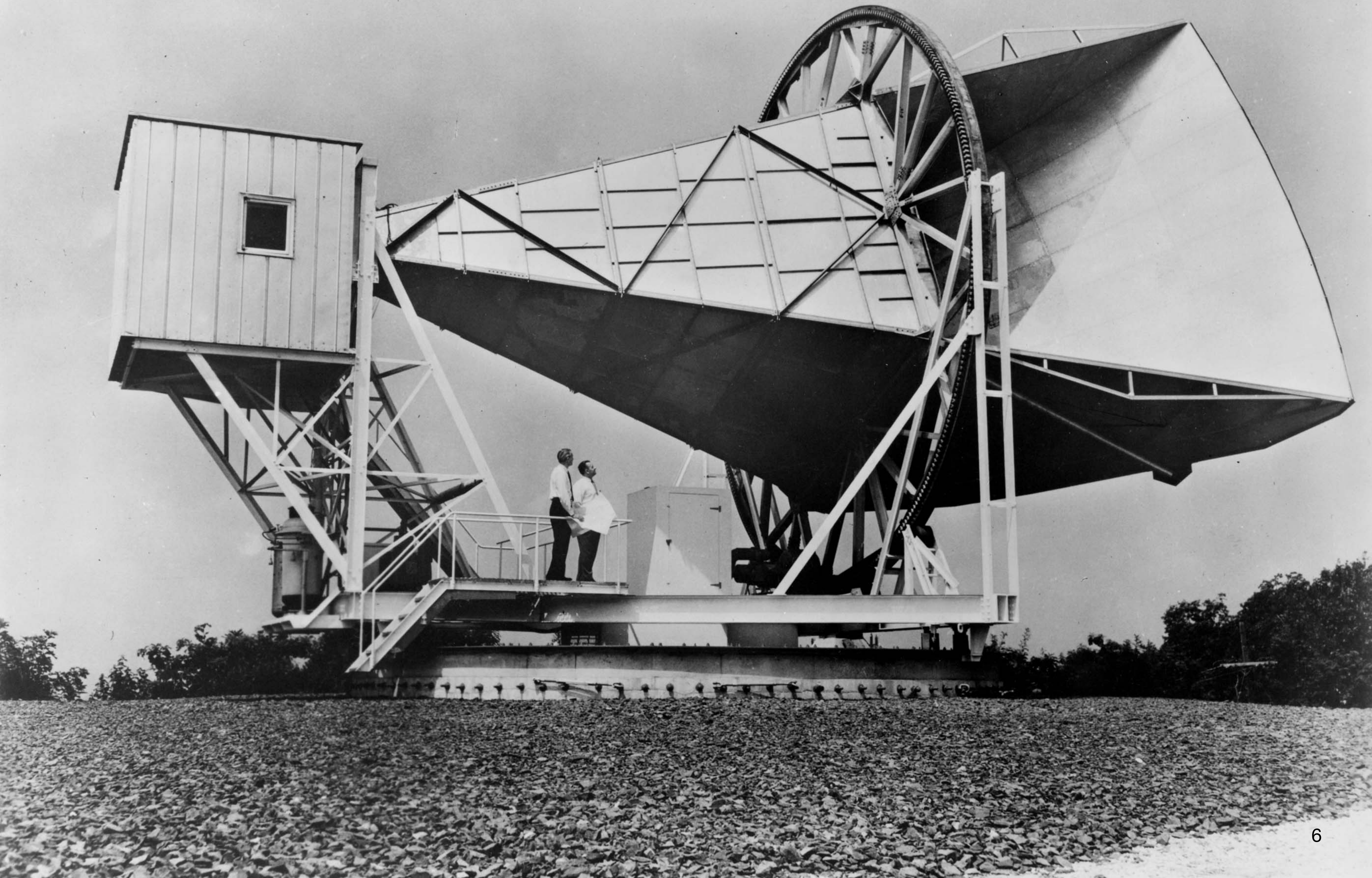


A Prediction

- Universe should be filled with CMB “light” left over from recombination
- Because of expansion of universe, light (aka “radiation”) is redshifted to ~3K or 160 GHz = microwaves
- Look for irreducible background of microwave radiation
- “Blackbody” radiation



Penzias and Wilson Detect CMB - 1964



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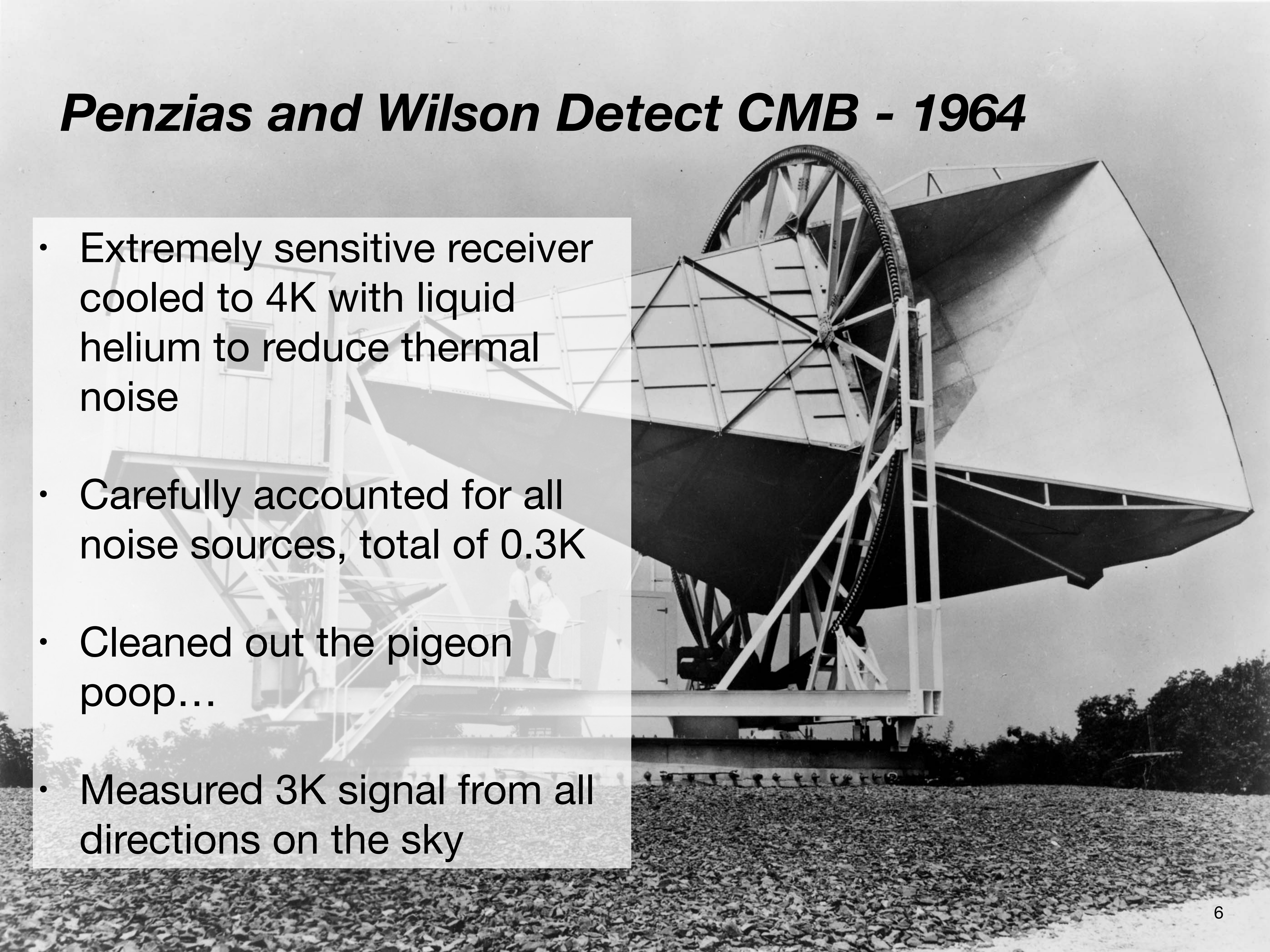


- Extremely sensitive receiver cooled to 4K with liquid helium to reduce thermal noise
- Carefully accounted for all noise sources, total of 0.3K
- Cleaned out the pigeon poop…
- Measured 3K signal from all directions on the sky

Penzias and Wilson Detect CMB - 1964

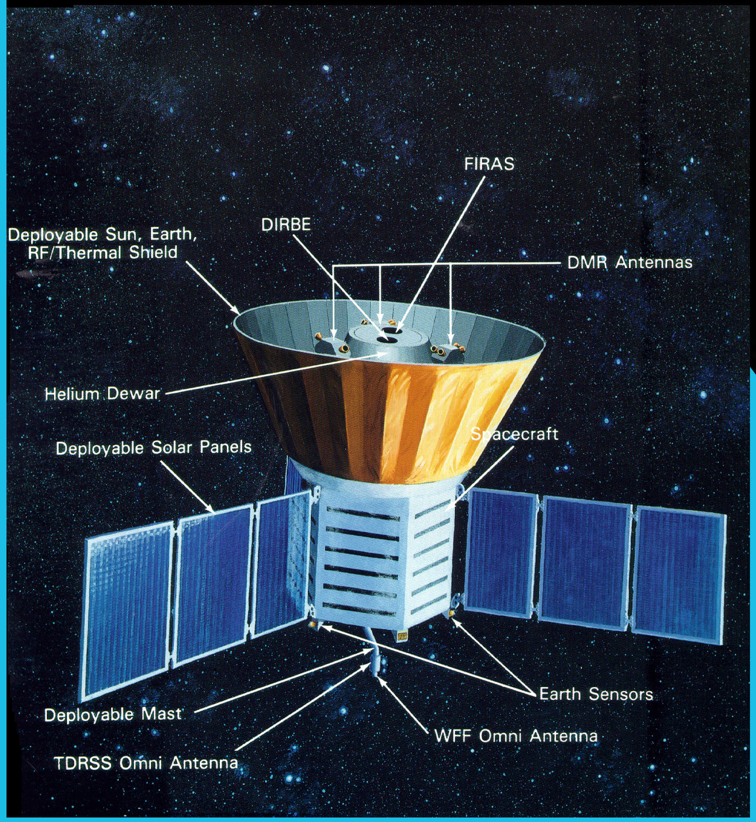
Conclusive evidence for Big Bang model!

Penzias and Wilson Detect CMB - 1964

Technology enables discovery

Cosmic Microwave Background Radiation

The COBE Satellite

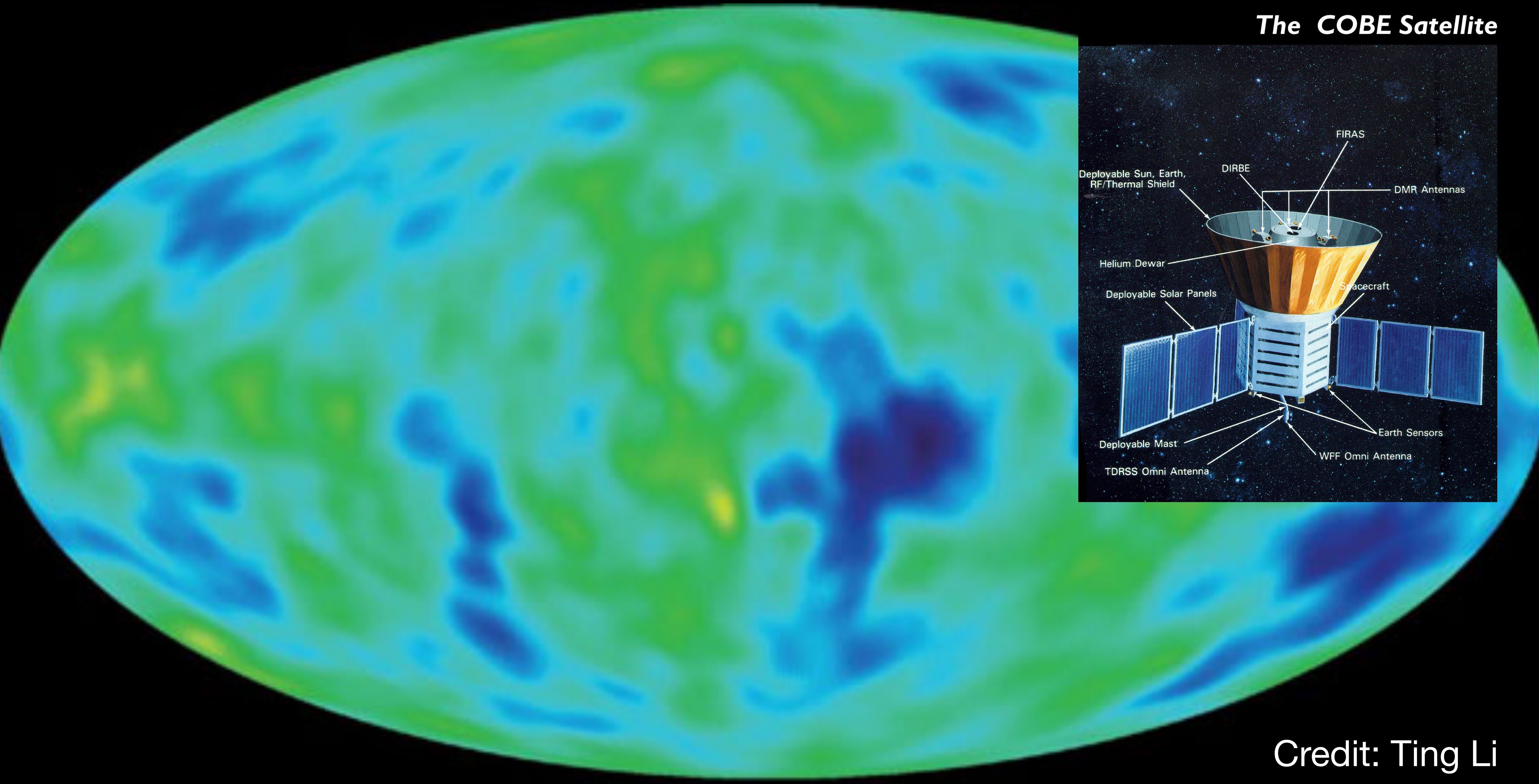


Credit: Ting Li

COBE Satellite

Temperature ~ 2.7 K

Cosmic Microwave Background Radiation



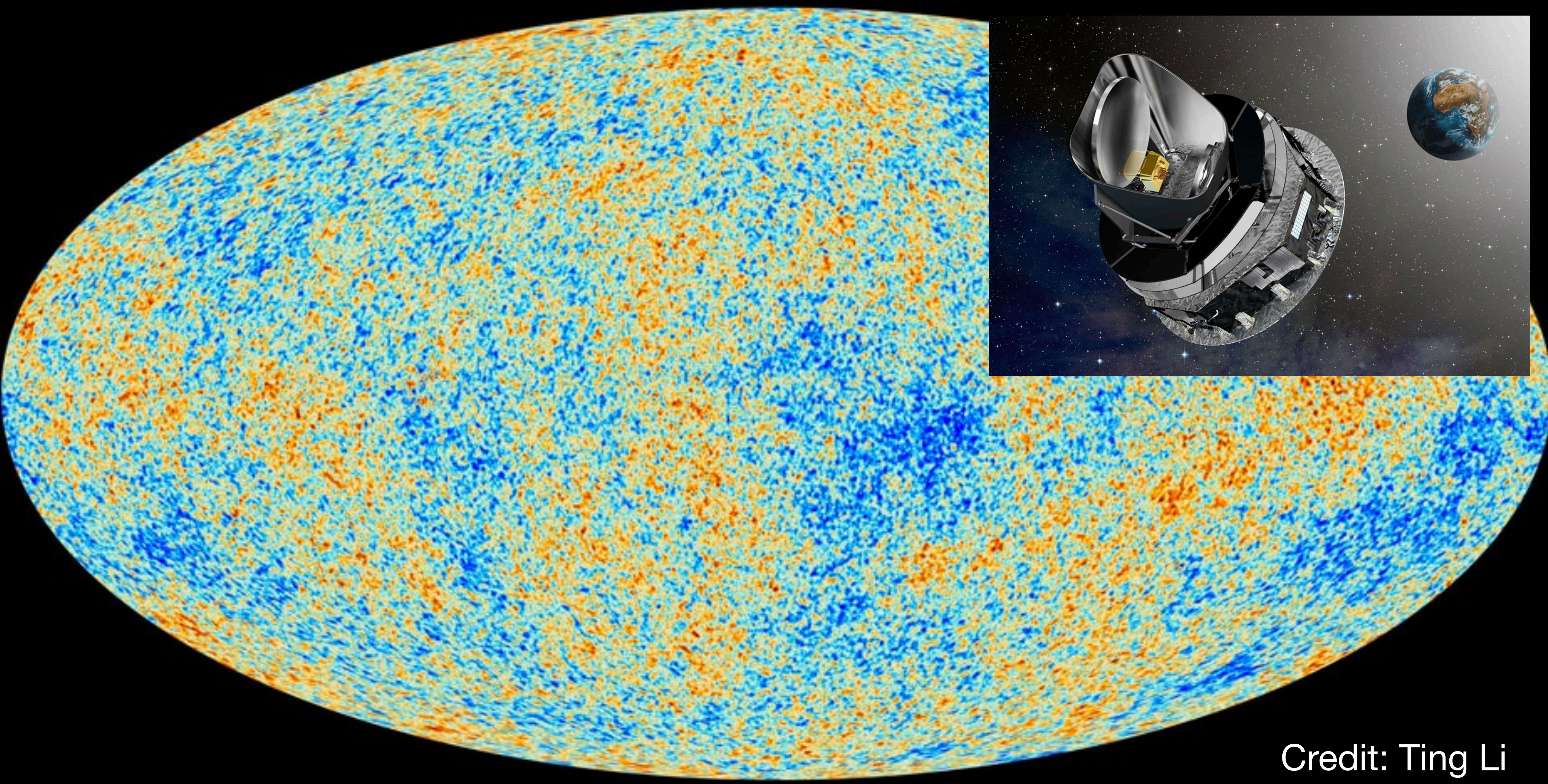
Credit: Ting Li

COBE Satellite

Temperature ~ 2.7 K

Temperature difference < 0.01 K

Cosmic Microwave Background Radiation



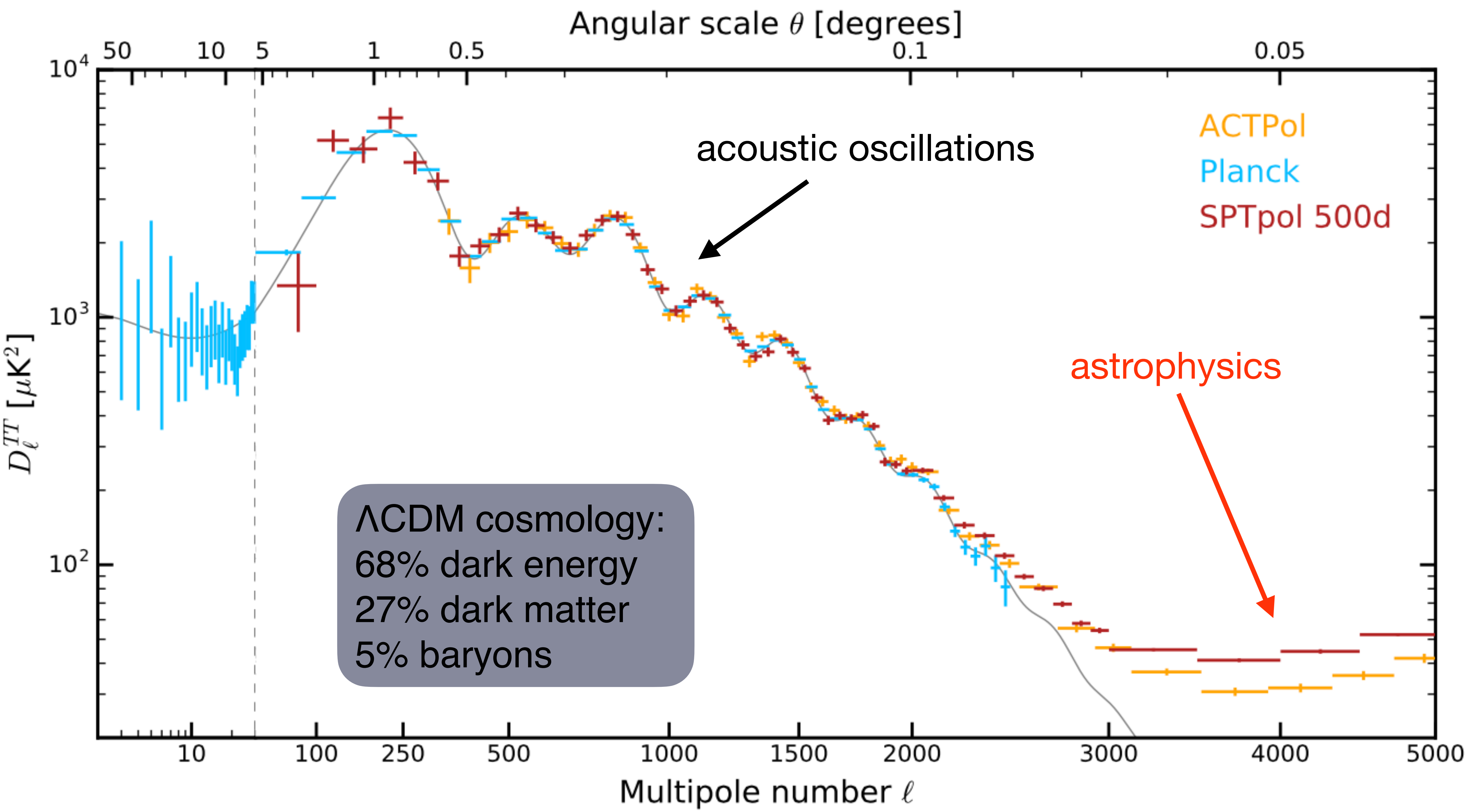
Credit: Ting Li

Planck Satellite

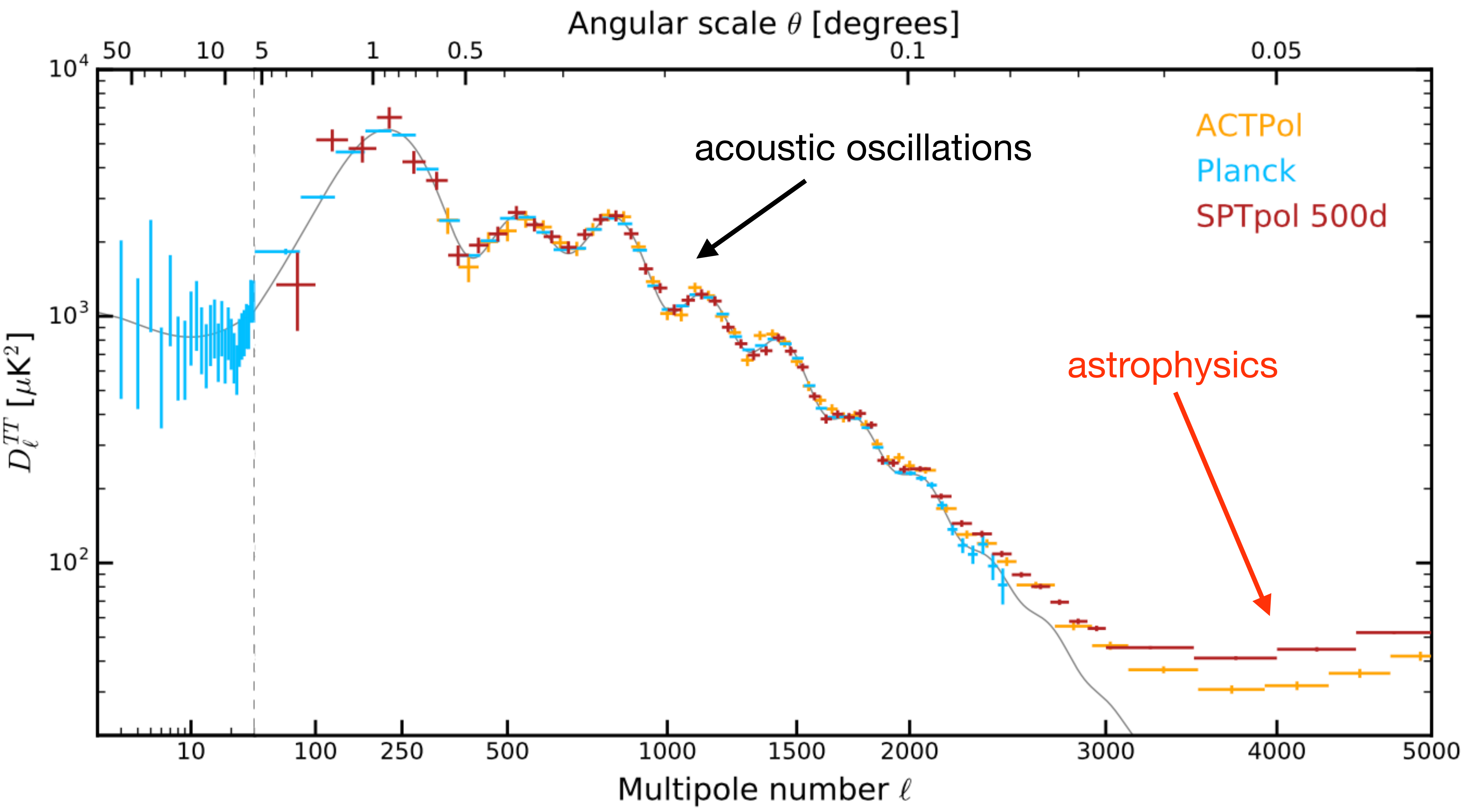
Temperature ~ 2.7 K

Temperature difference < 0.01 K

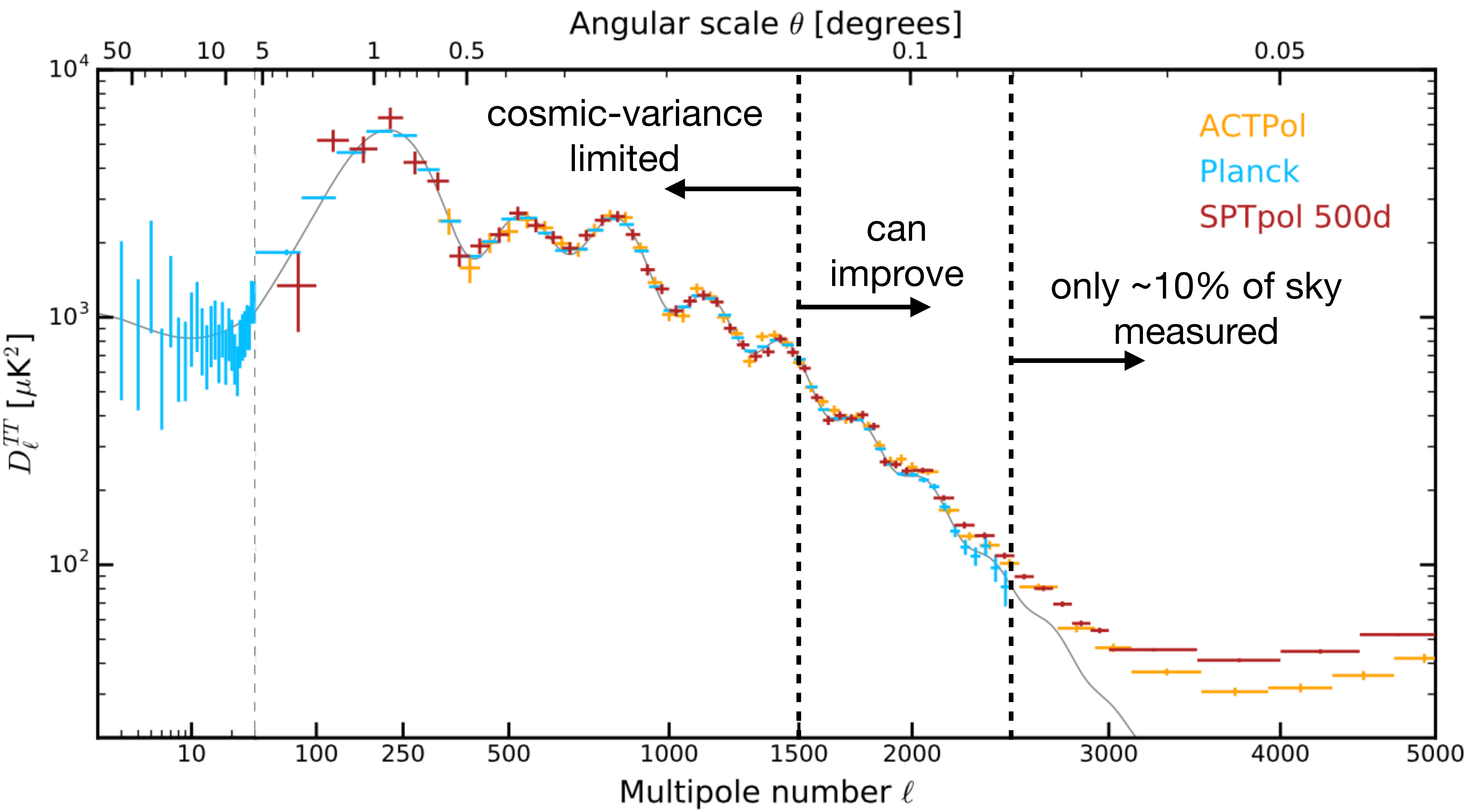
From Maps to Power Spectra



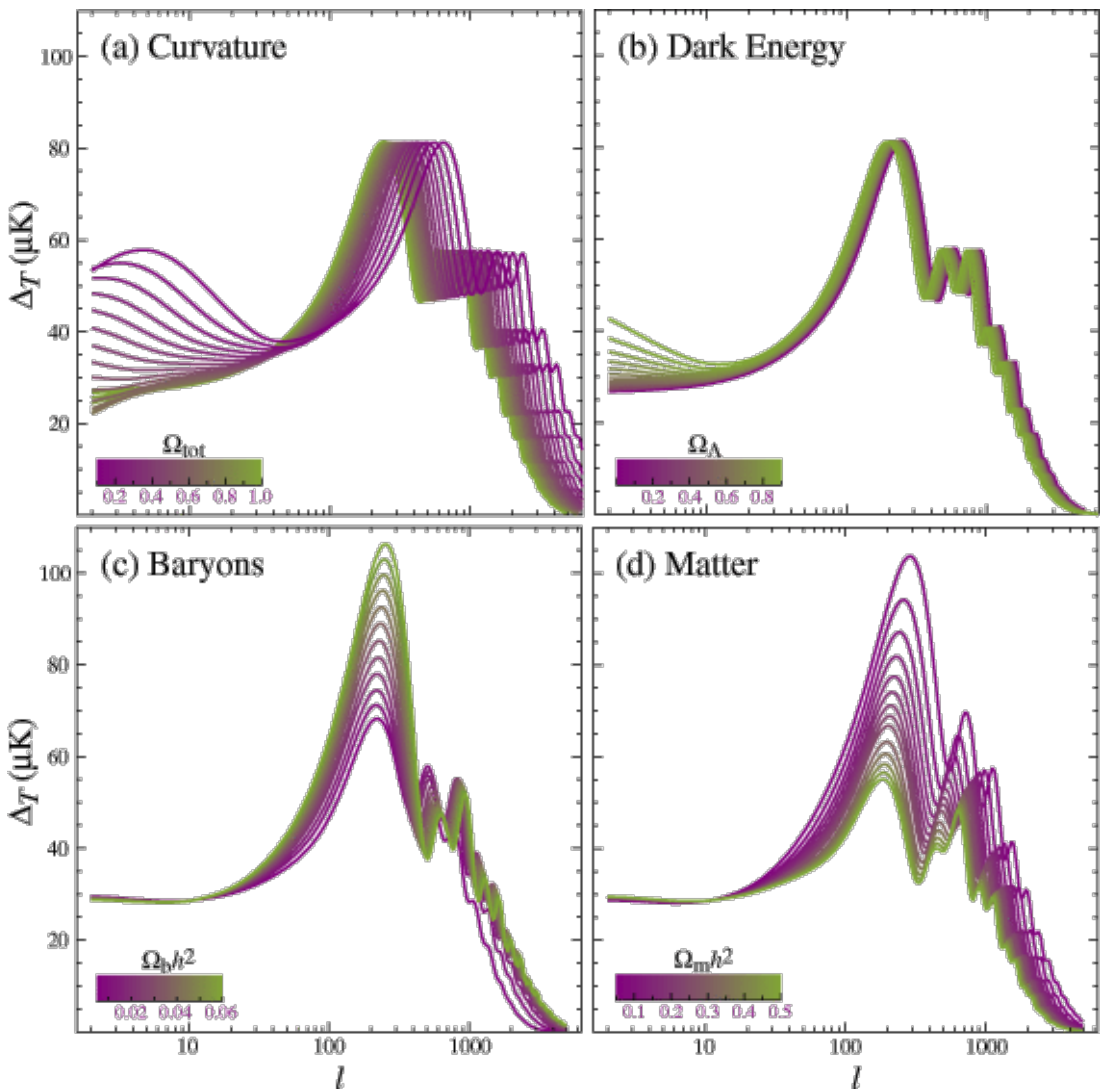
From Maps to Power Spectra



From Maps to Power Spectra



Why the power spectrum is useful



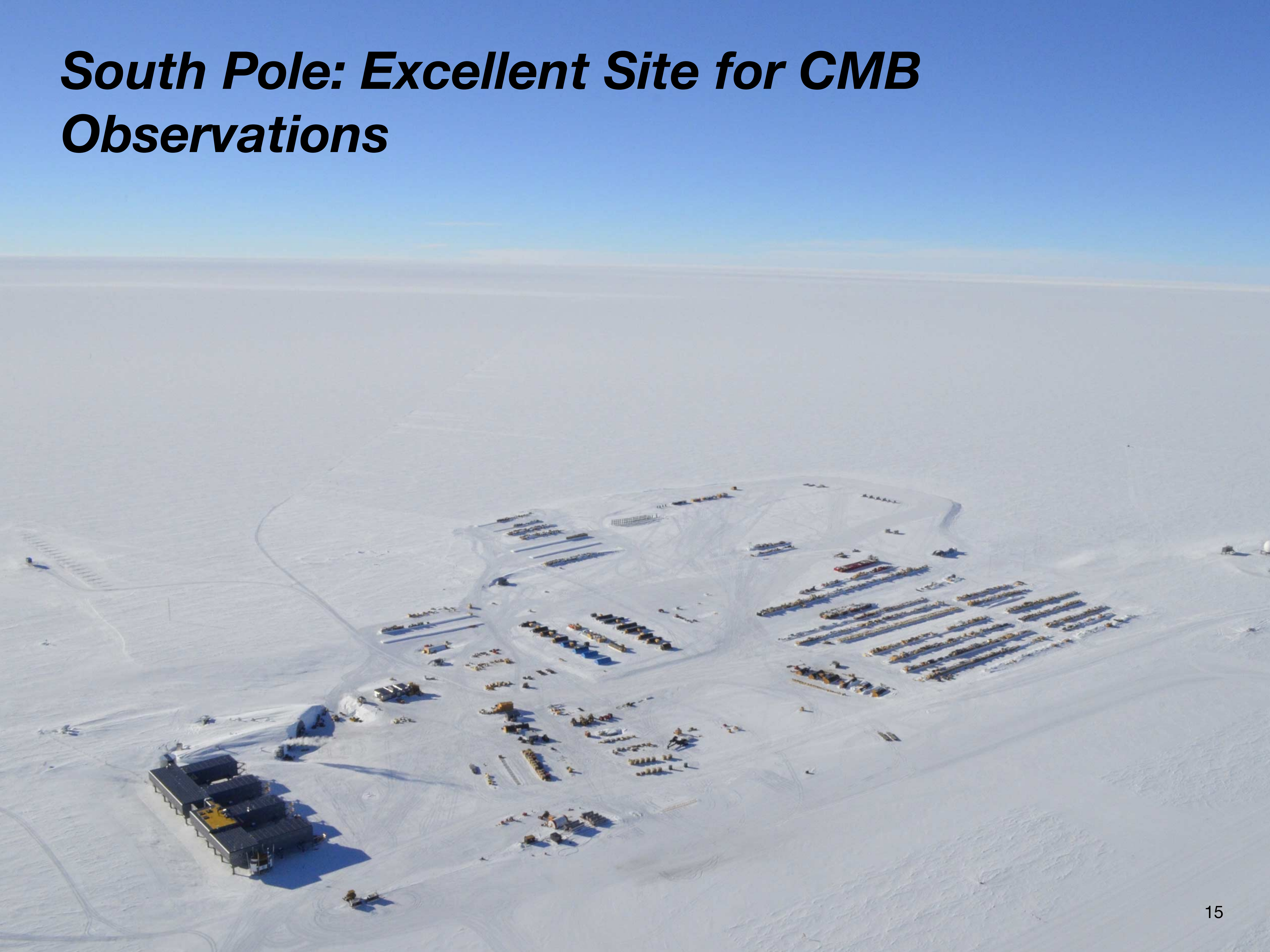
Sensitive to the entire matter/energy budget!


Arctic Ocean
East Siberian Sea
Baffin Bay
NU
AK
YT
NT
Canada
NL
AB
SK
QC
BC
Sea of Okhotsk
Bering Sea
NB
ND
MN
WI
NH
WA
MT
SD
PA
OR
ID
WY
Sea of Japan
Japan
NV
UT
CO
MO
KY
NC
OK
CA
AZ
NM
AL
TX
LA
East China Sea
FL
North Pacific Ocean
Mexico
Cuba
Philippine Sea
Caribbean Sea
Philippines
HI
Nicaragua
Colombia
Ecuador
Banda Sea
Papua New Guinea
Peru
NT
Coral Sea
SA
NSW
VIC
South Pacific Ocean
TAS
New Zealand
Google
Southern Ocean
Map data ©2018 Google, INEGI
United States
Terms


Papua New Guinea
QLD
NT
NSW
Australia
VIC
SA
TAS
Great Australian Bight
WA
New Zealand
South Pacific Ocean
Southern Ocean
Peru
AC
Chile
Argentina
MS
Uruguay
SC
RJ
Indian Ocean
ANTARCTICA
Google


Geographic South Pole
Roald Amundsen
December 14, 1911
"So we arrived and were able to plant our flag at the geographical South Pole."
Robert F. Scott
January 17, 1912
"The Pole. Yes, but under very different circumstances from those expected."
elevation 9,301 feet

South Pole: Excellent Site for CMB Observations



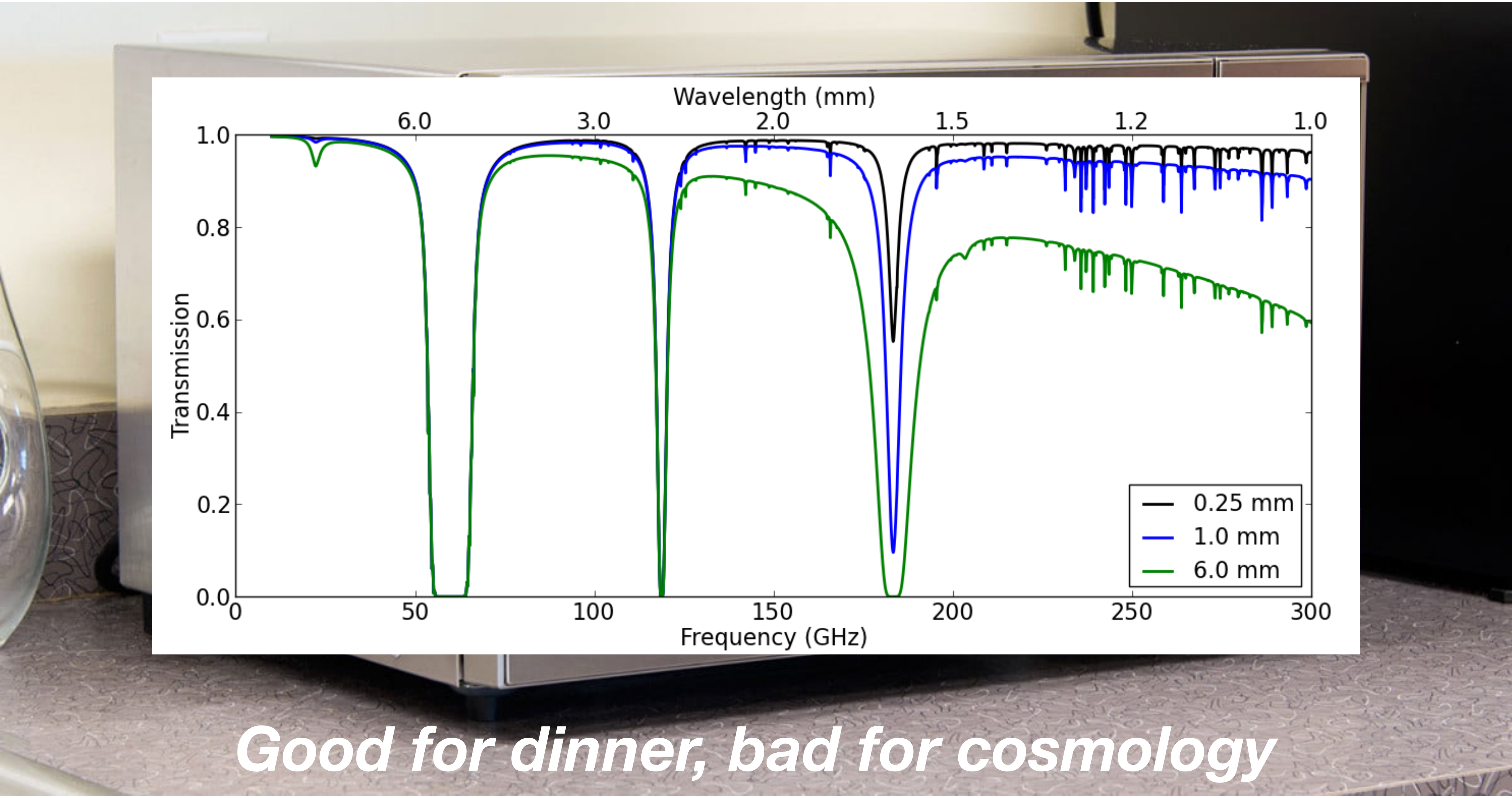
South Pole: Excellent Site for CMB Observations

- High elevation: 10,000 feet
- Extremely dry atmosphere
- Stable observing conditions

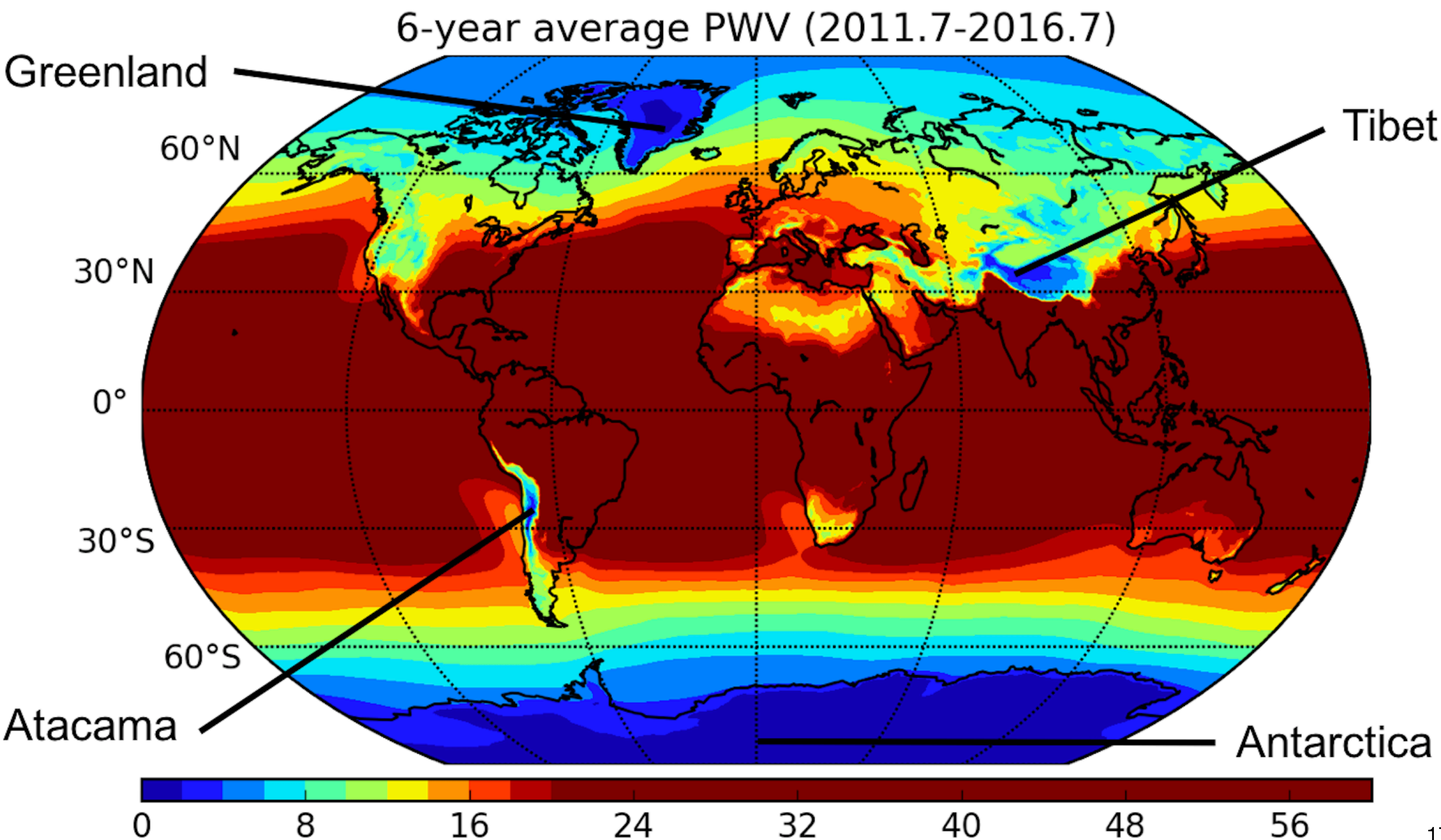
Water Absorbs Microwaves

Good for dinner, bad for cosmology

Water Absorbs Microwaves



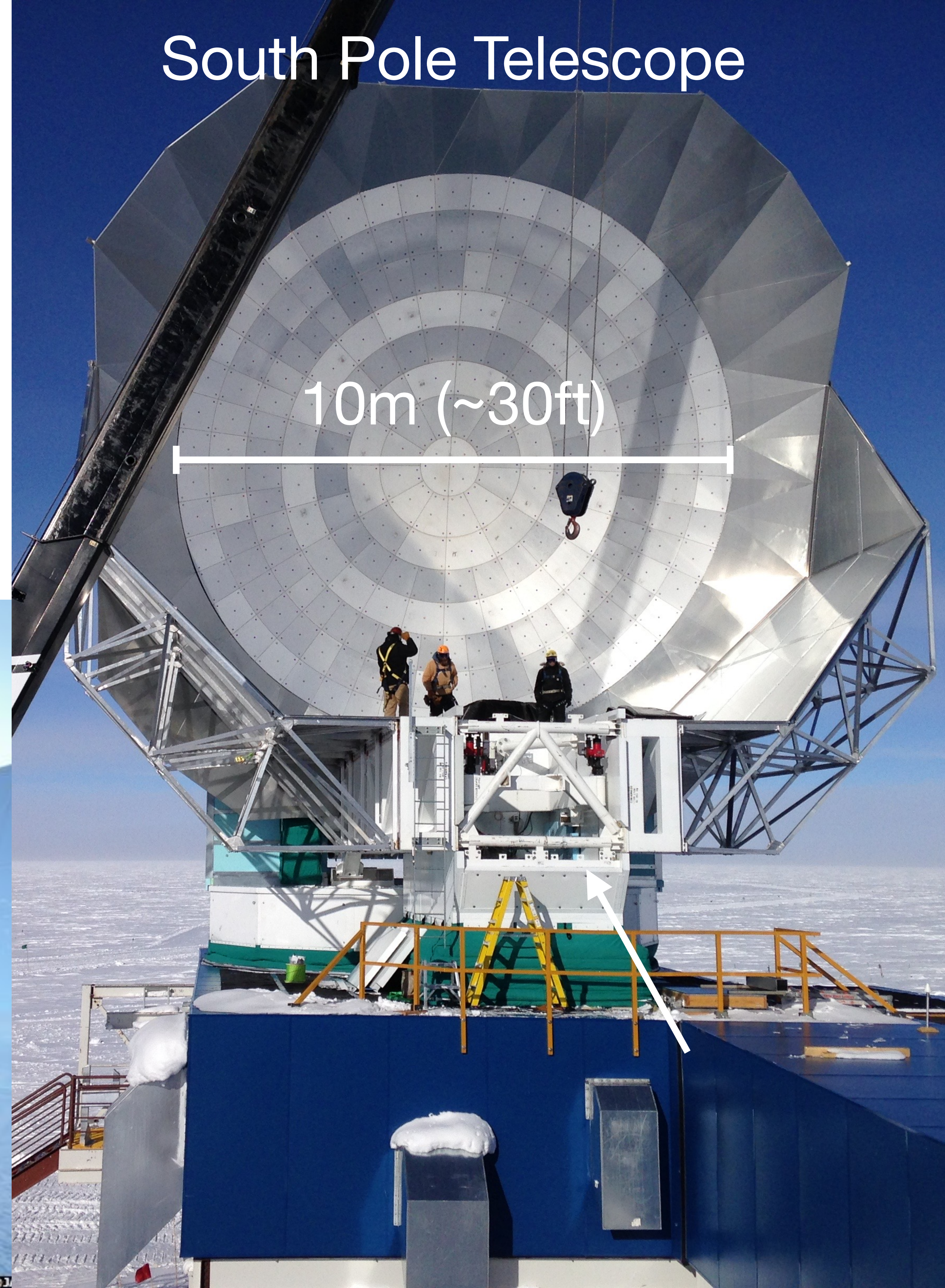
Where to Go?



6-year average PWV (2011.7-2016.7)
Greenland
Tibet
60°N
30°N
0°
30°S
60°S
Atacama
Antarctica
0
8
16
24
32
40
48
56

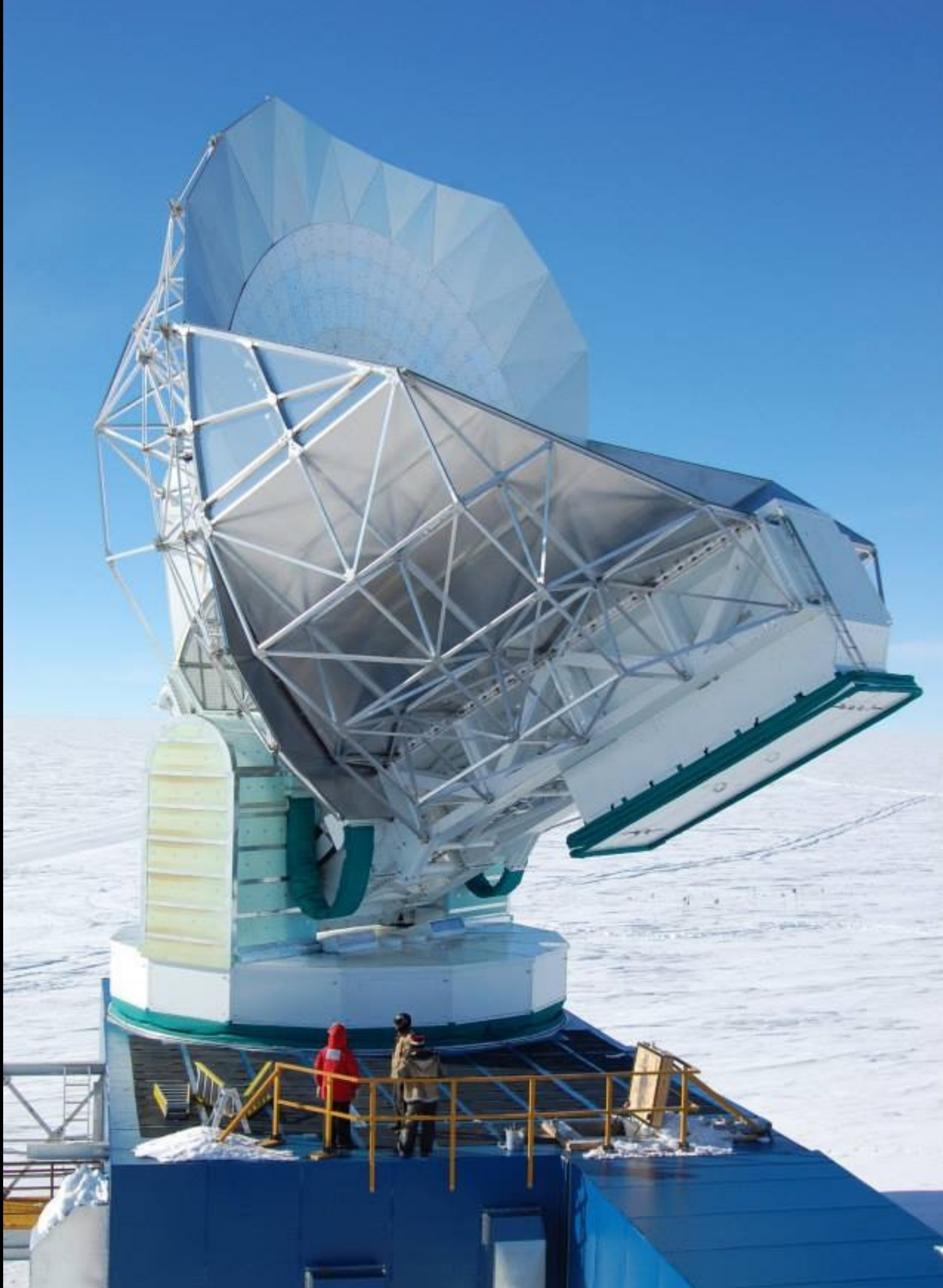
Telescopes

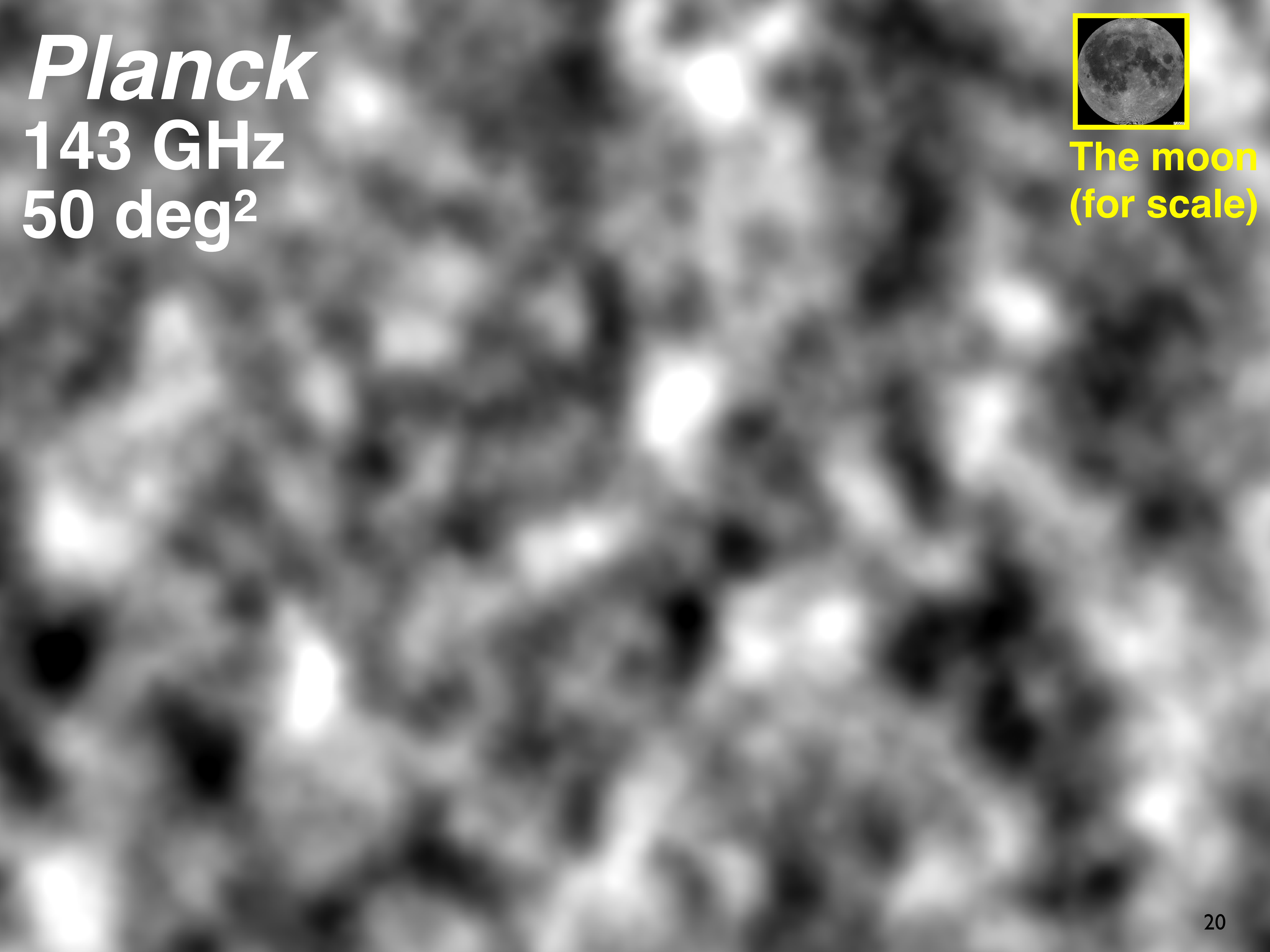
- Large mirror = high resolution, but expensive
- Small refractor = low resolution, but cheap

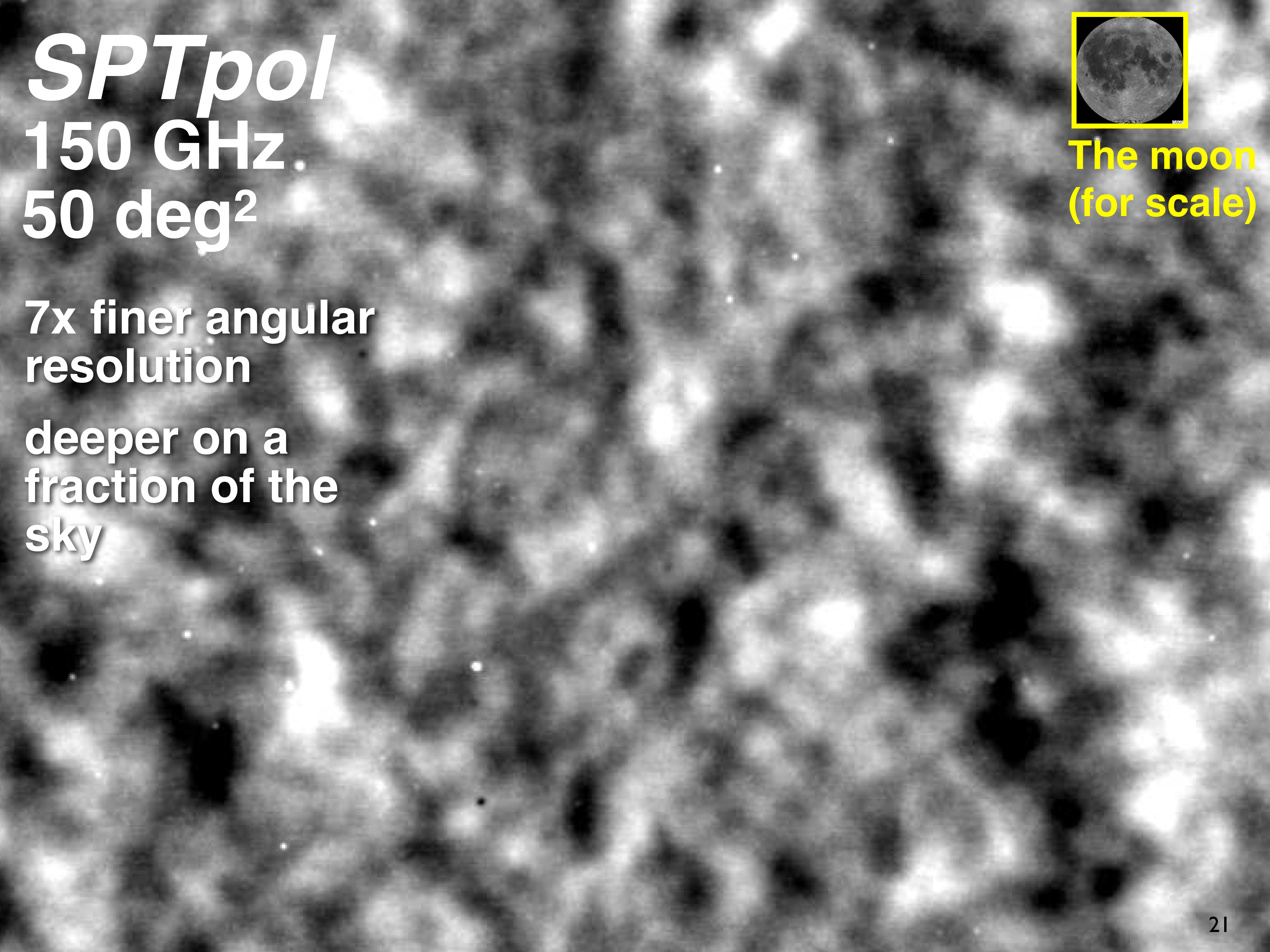


The South Pole Telescope (SPT)

- Unique 10 m primary mirror, largest of its kind
- resolution of ***1.0 to 1.5 arcmin***, highest resolution CMB maps
- South Pole is an excellent site:
  - dry
  - extremely stable atmosphere
  - 24/7 access to the same clean patches of sky (“relentless” observing)




Planck
143 GHz
50 deg²
The moon
(for scale)



SPTpol

150 GHz
50 deg^2

7x finer angular resolution

deeper on a fraction of the sky

The moon (for scale)

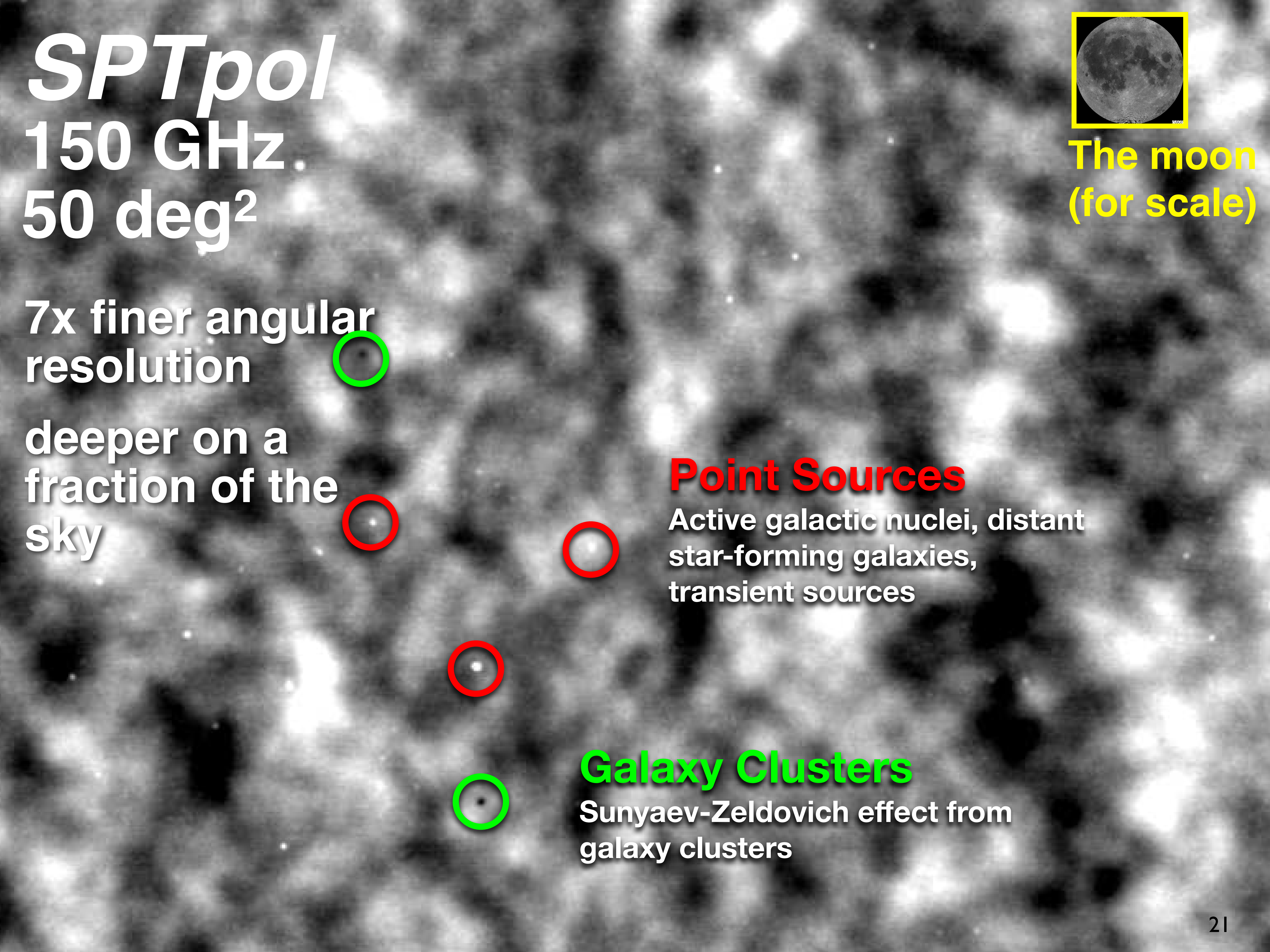
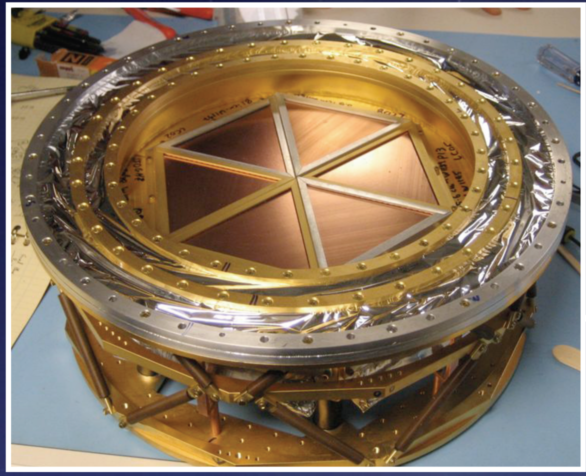

SPTpol
150 GHz
50 deg²
7x finer angular resolution
deeper on a fraction of the sky
The moon (for scale)
Point Sources
Active galactic nuclei, distant star-forming galaxies, transient sources
Galaxy Clusters
Sunyaev-Zeldovich effect from galaxy clusters

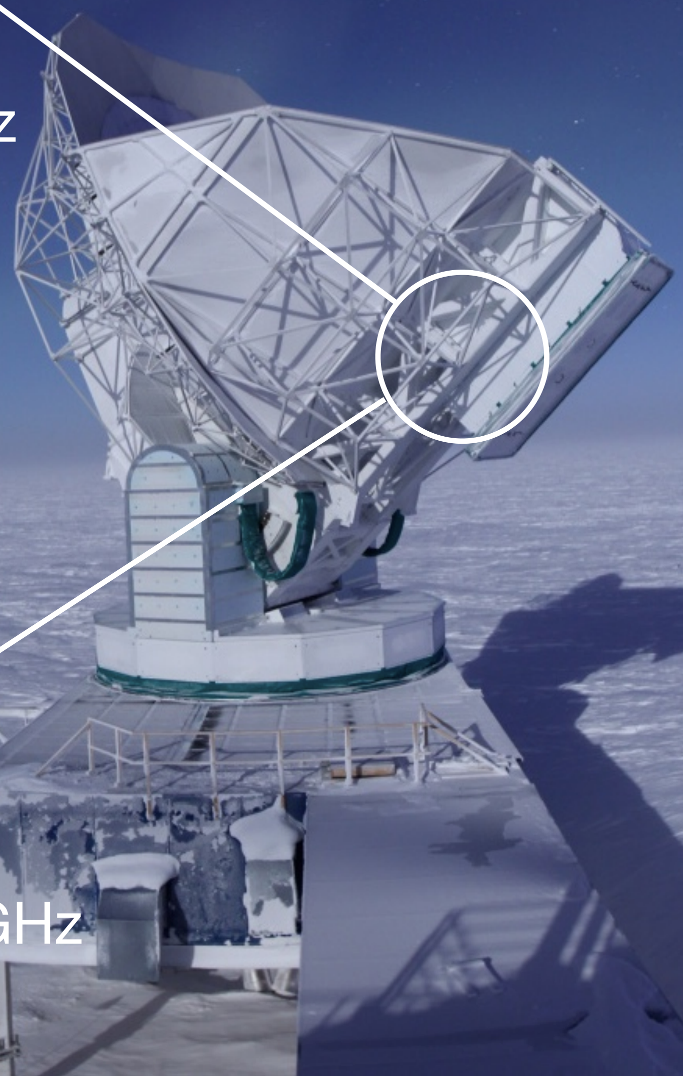
photo credit: Jason Gallicchio

South Pole Telescope

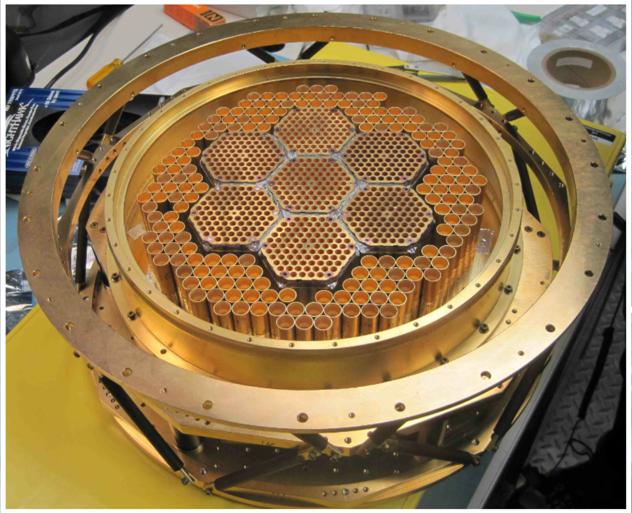
SPT-SZ (2007)



960 detectors at 95, 150, 220 GHz



SPTpol (2012)



1500 detectors at 95, 150 GHz
w/polarization

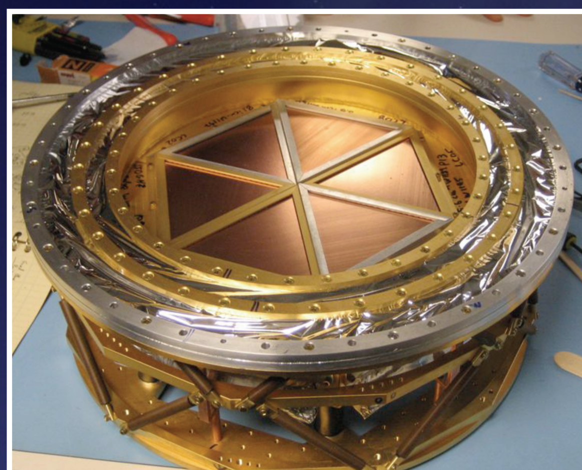
photo credit: Jason Gallicchio

South Pole Telescope

SPT-3G (2017)

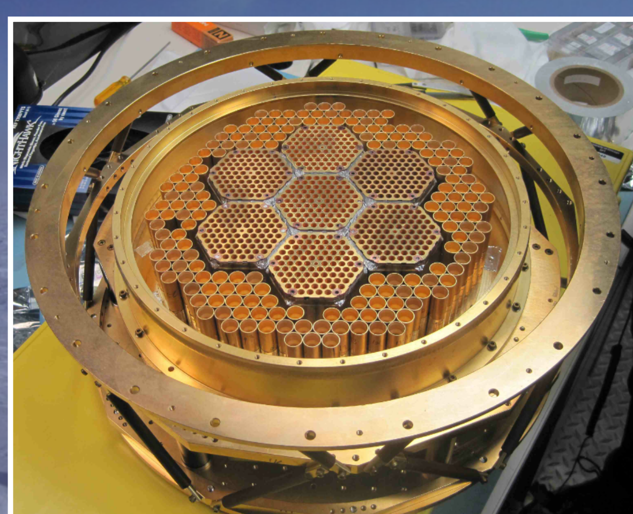
15,000 detectors at 95, 150, 220 GHz
w/polarization

SPT-SZ (2007)



960 detectors at 95, 150, 220 GHz

SPTpol (2012)

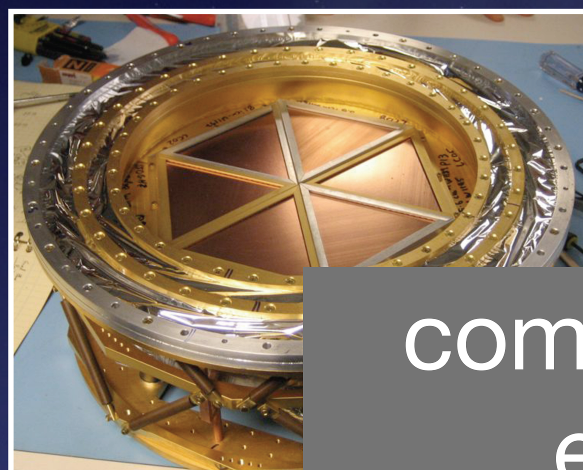


1500 detectors at 95, 150 GHz
w/polarization

photo credit: Jason Gallicchio

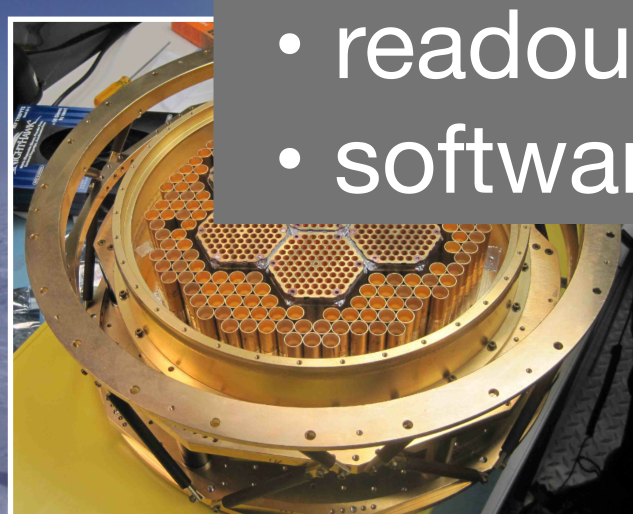
South Pole Telescope

SPT-SZ (2007)



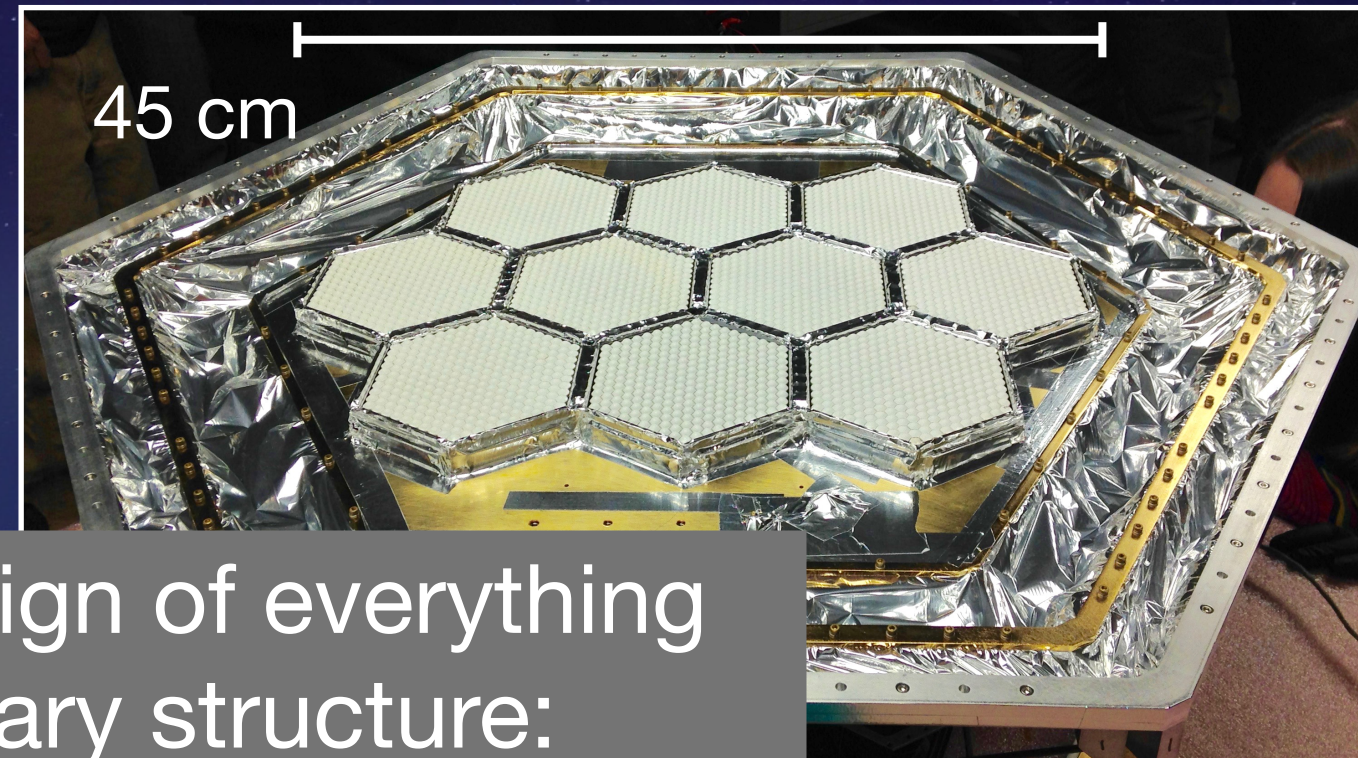
960 detectors at 9

SP



1500 detectors at 95, 150 GHz
w/polarization

SPT-3G (2017)

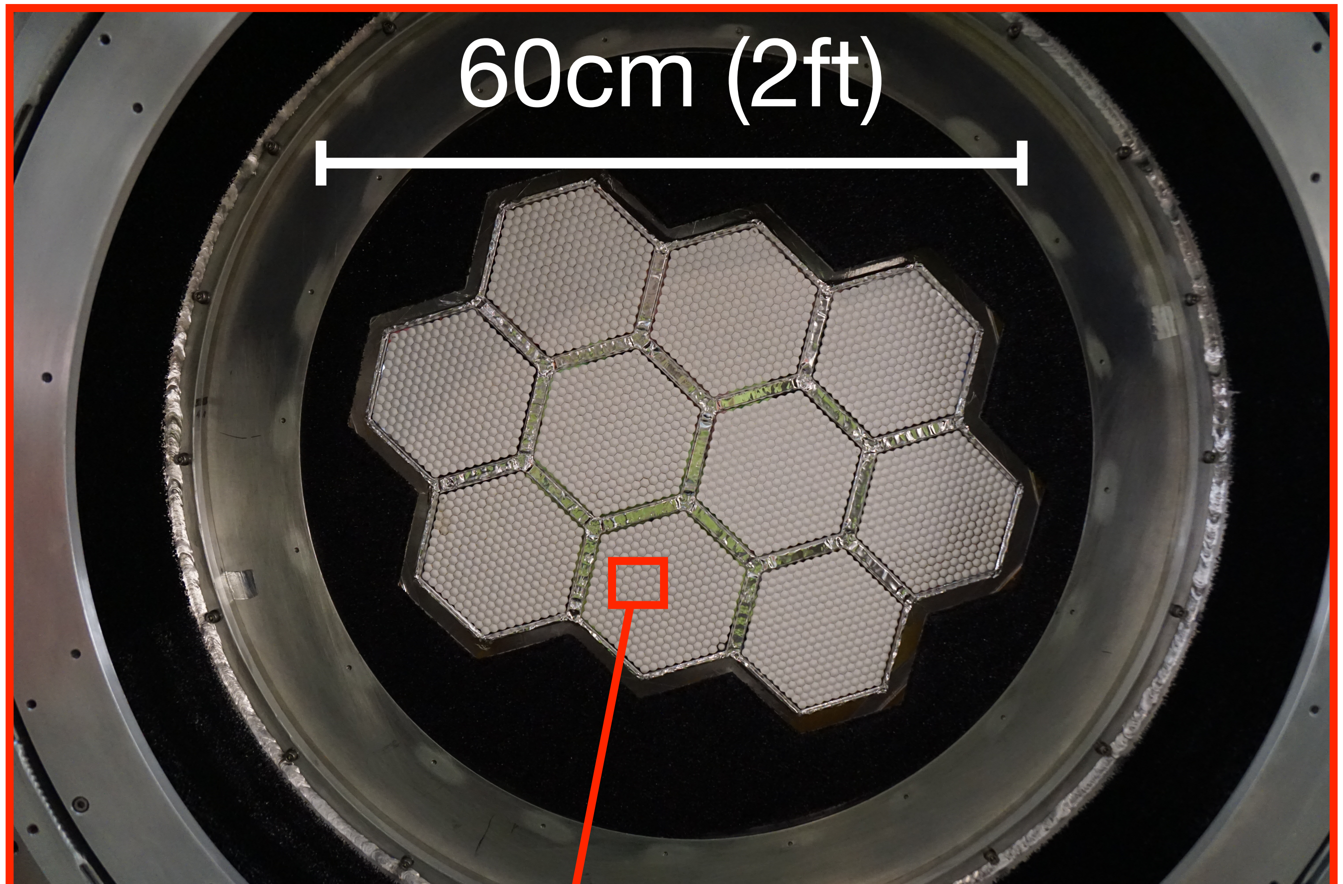


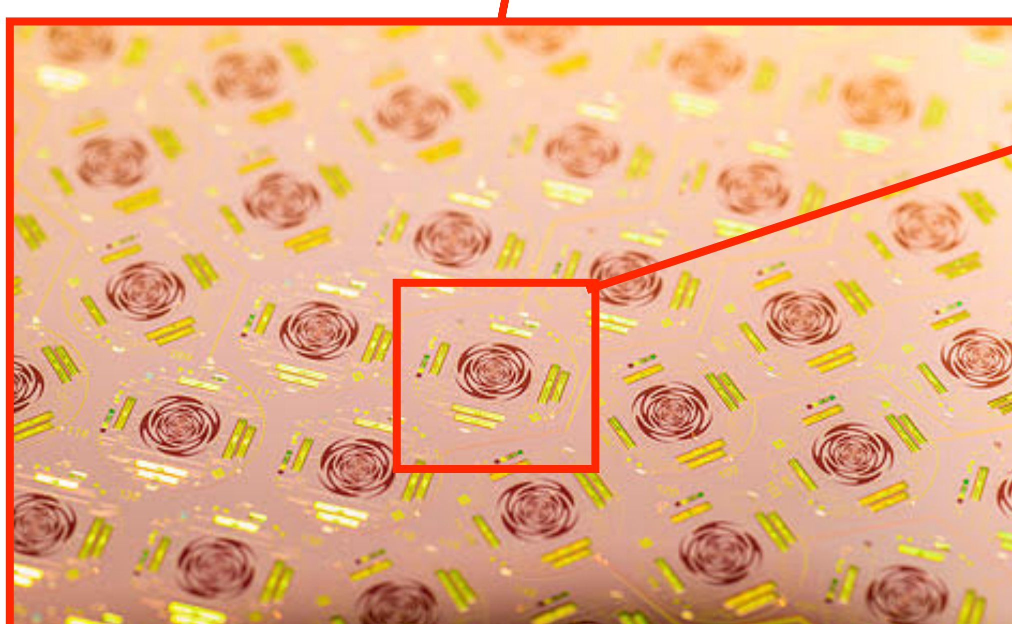
, 150, 220 GHz
ion

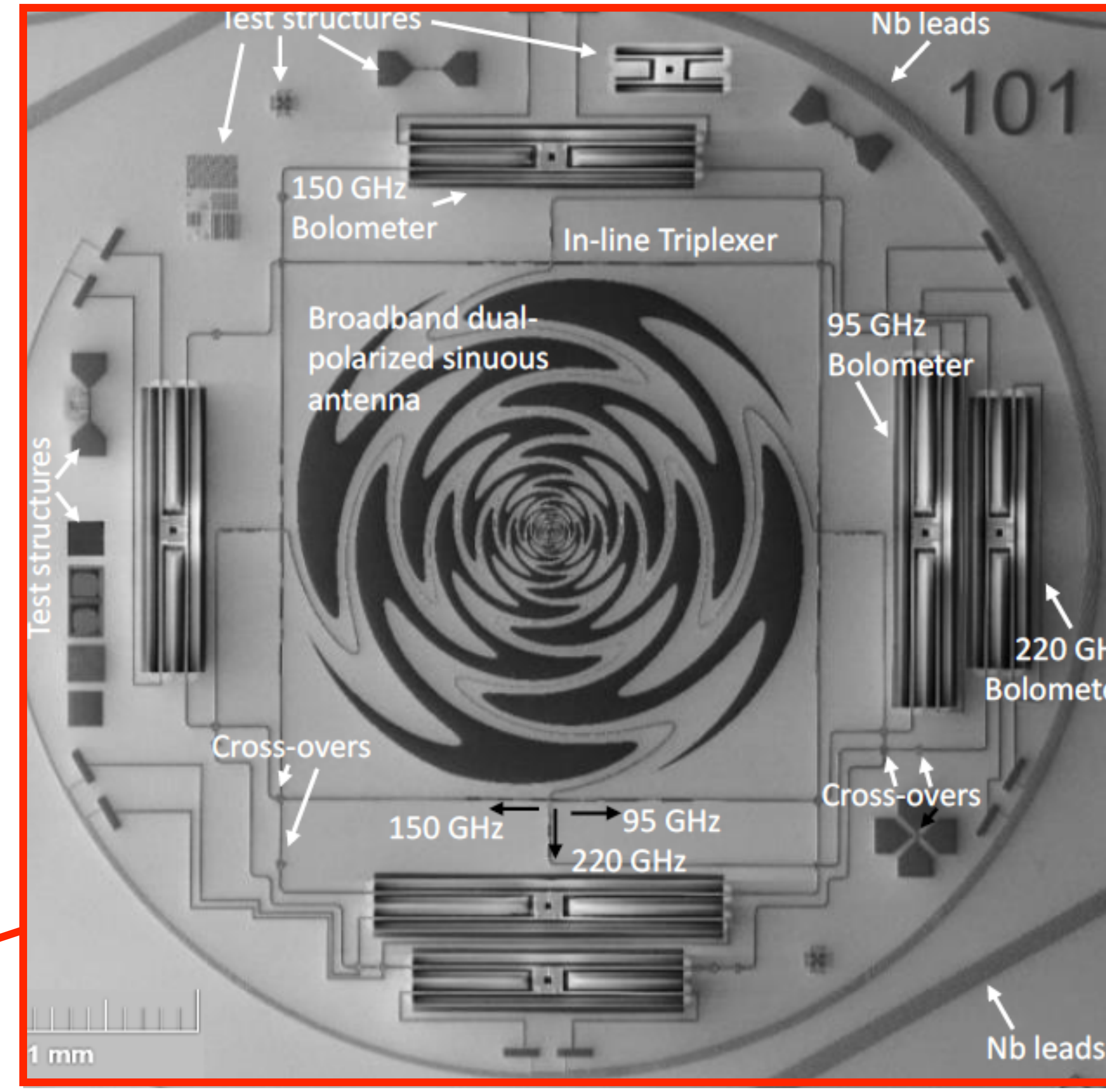
complete redesign of everything except primary structure:

- secondary optics
- detectors
- readout electronics
- software

Detectors

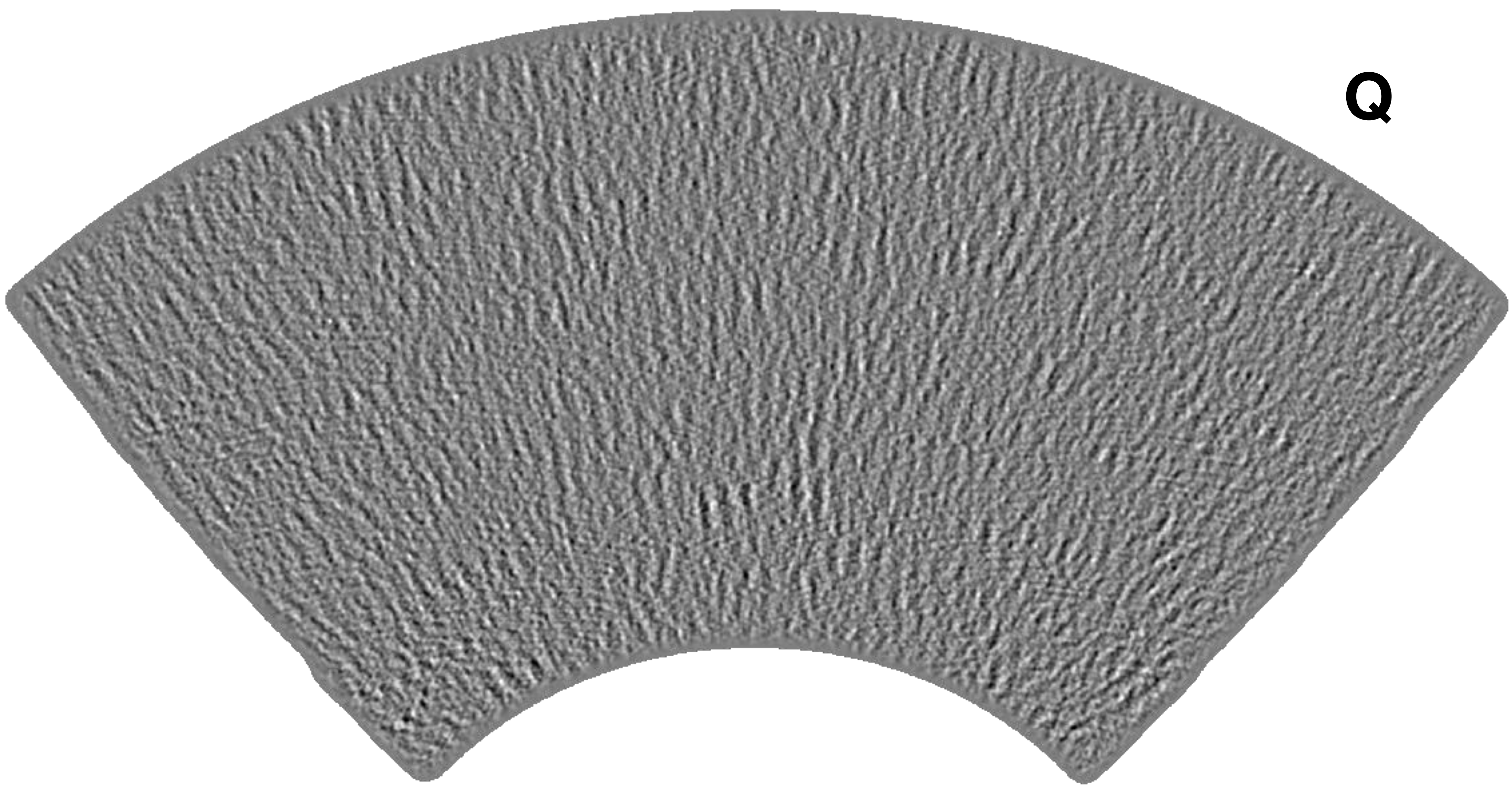






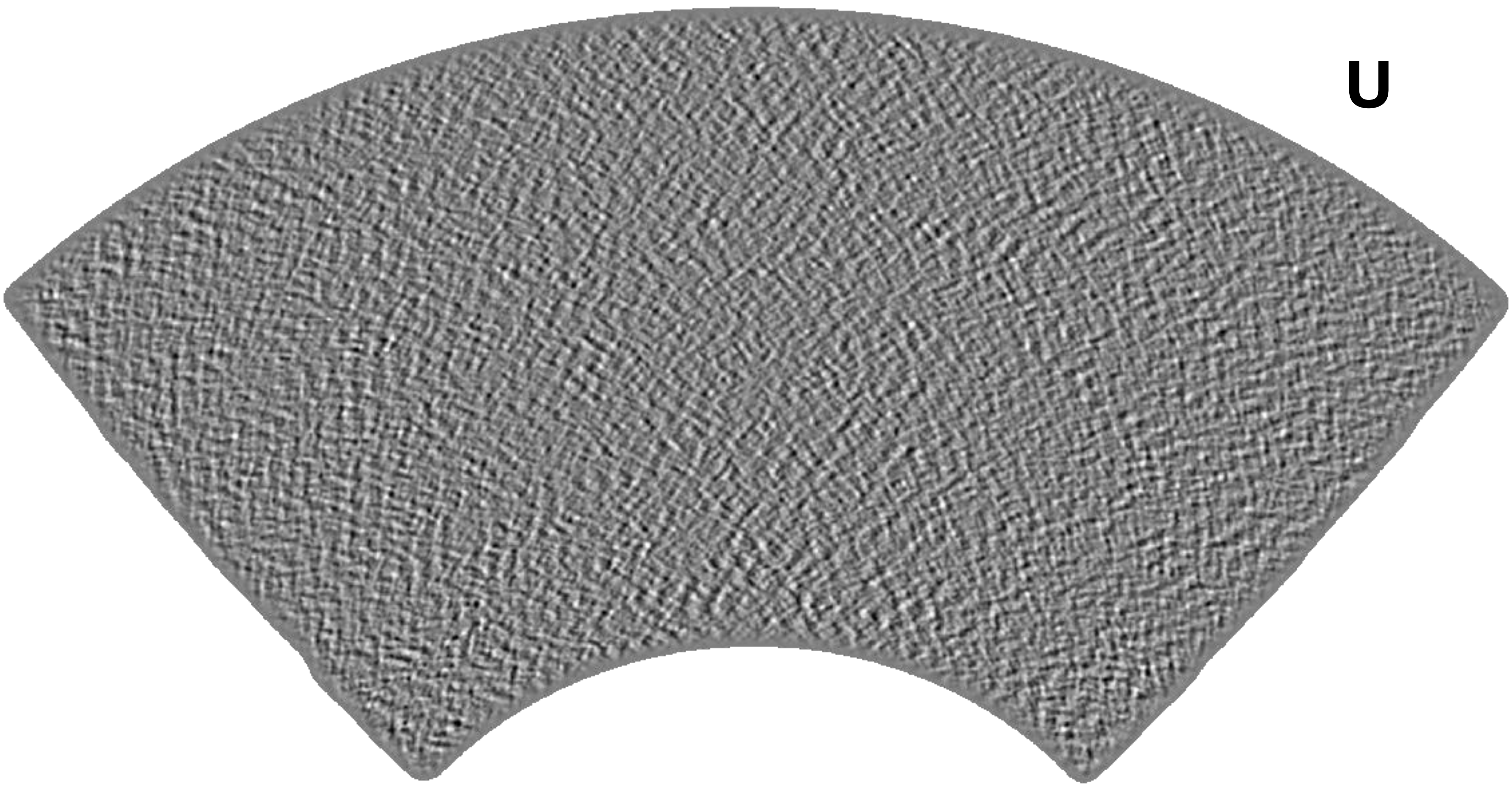
Use superconducting detectors at 0.3 degrees above absolute zero!

SPT-3G 2018 E Modes

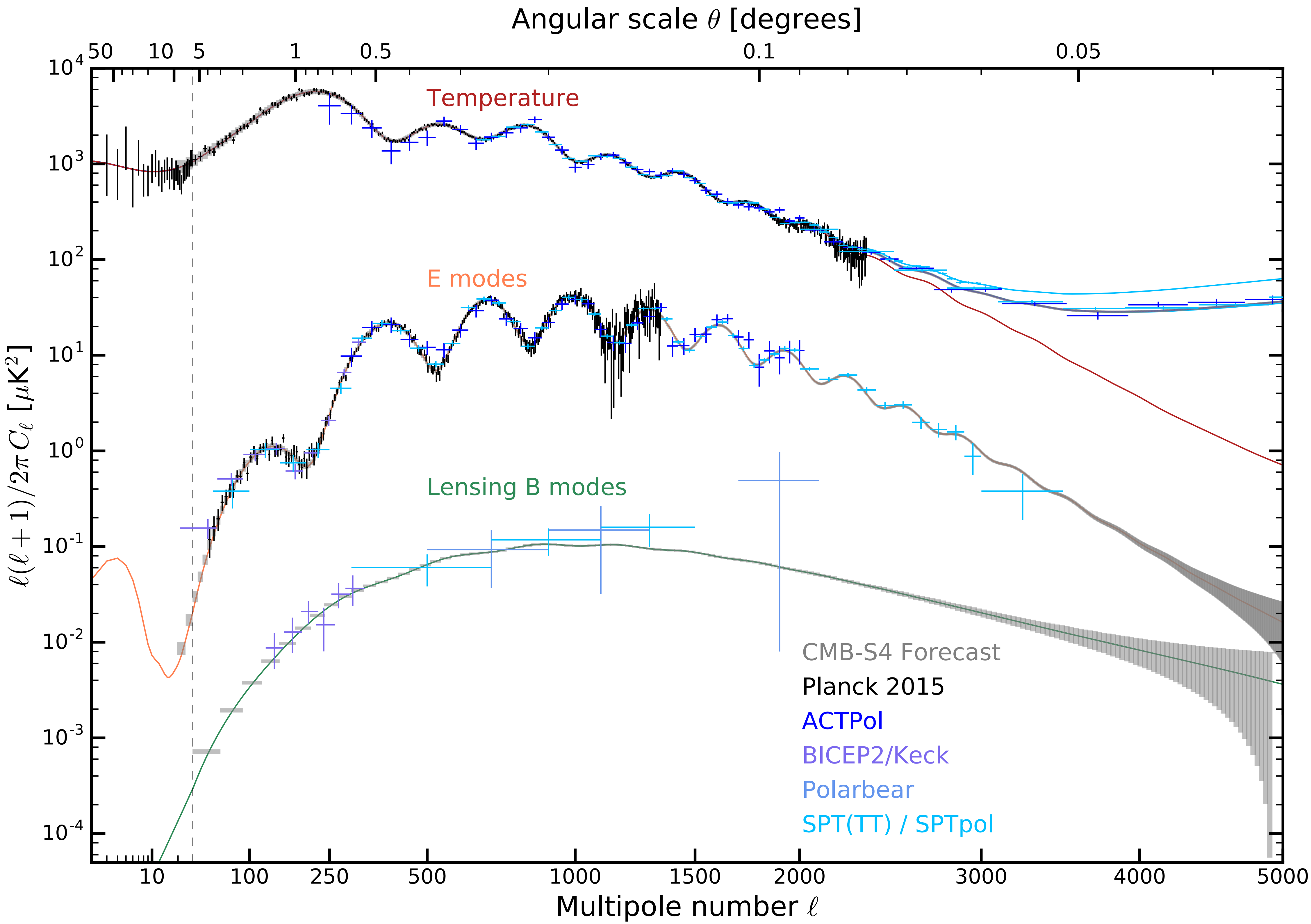


Q

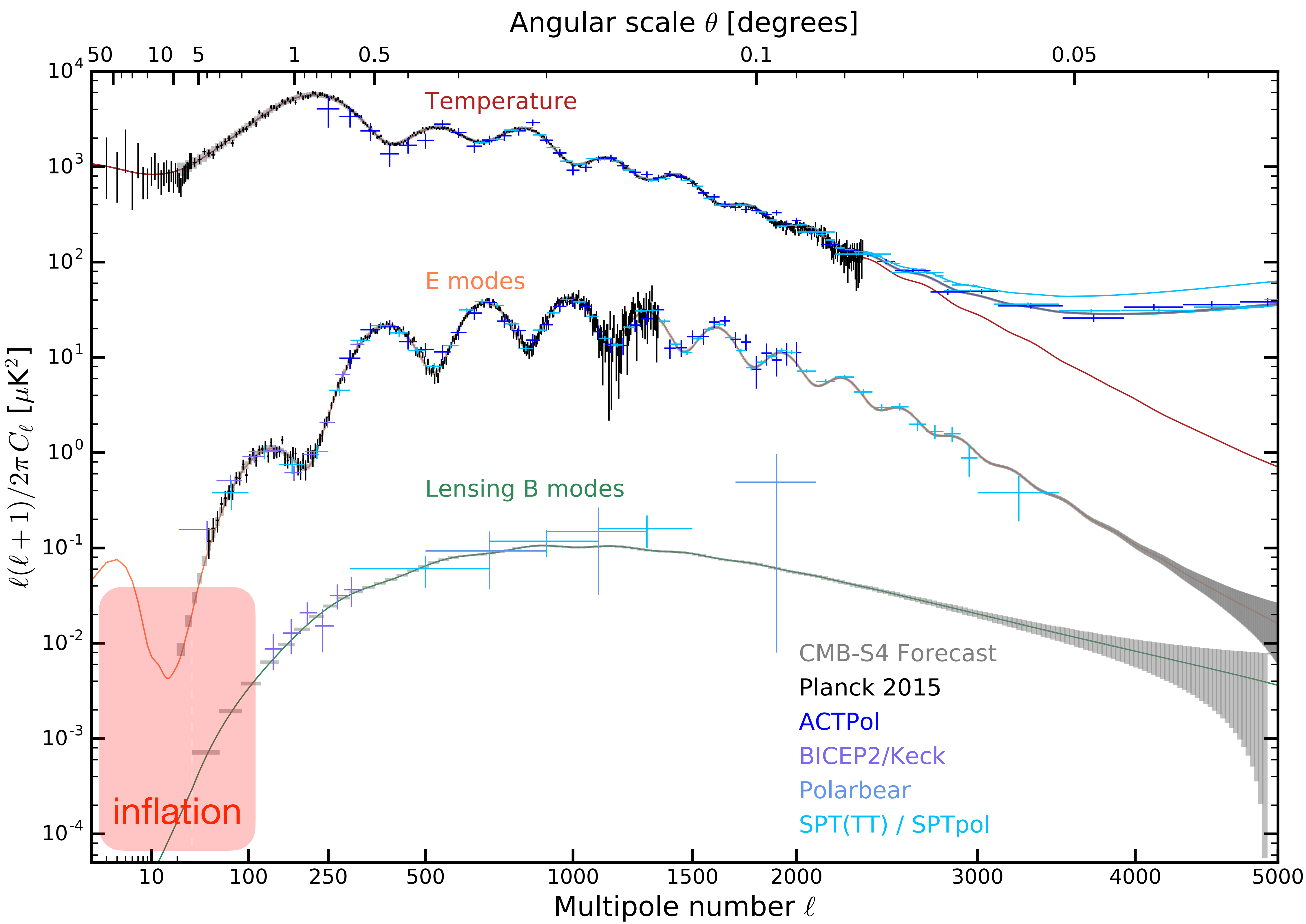
SPT-3G 2018 E Modes



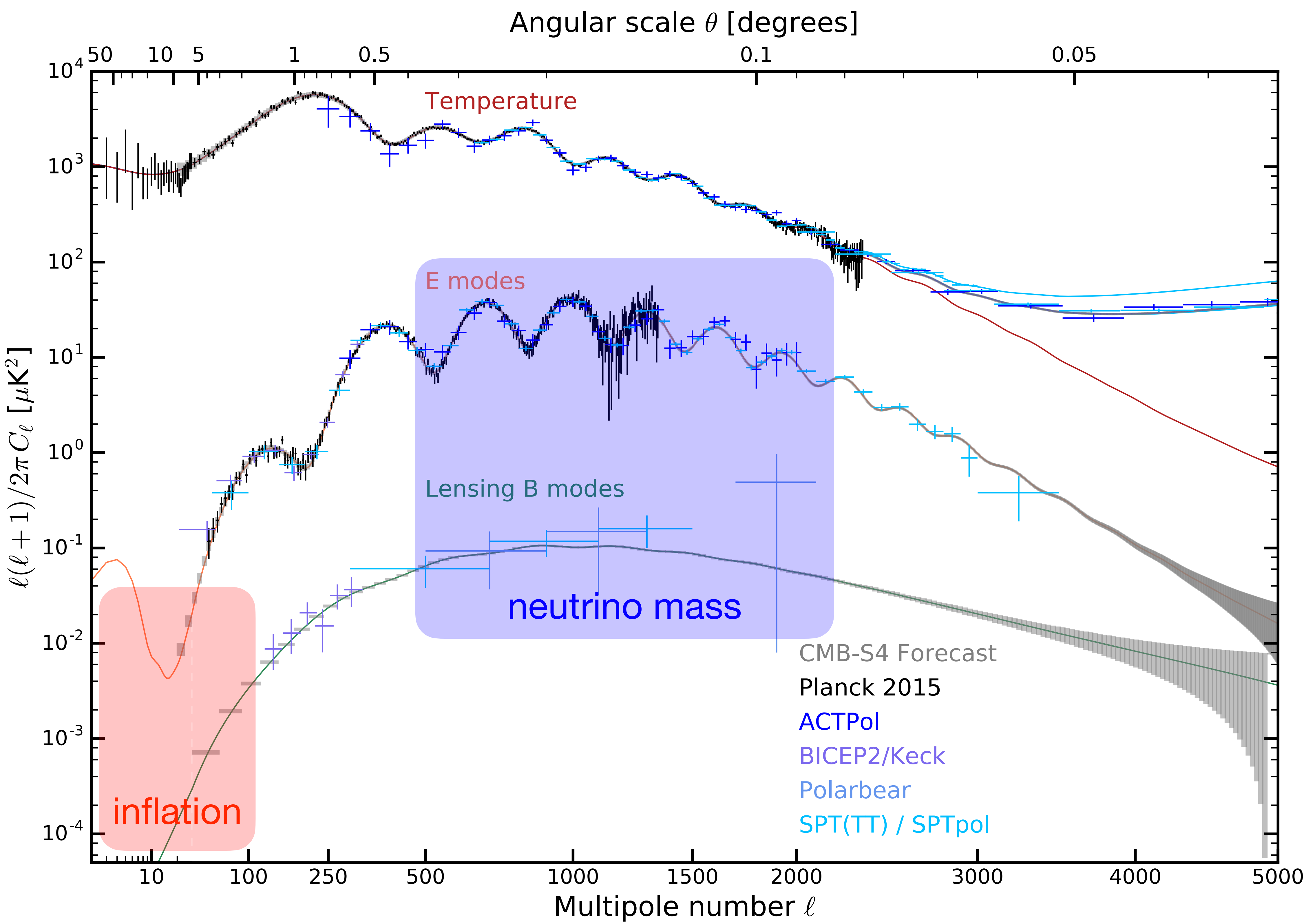
Polarization Power Spectrum



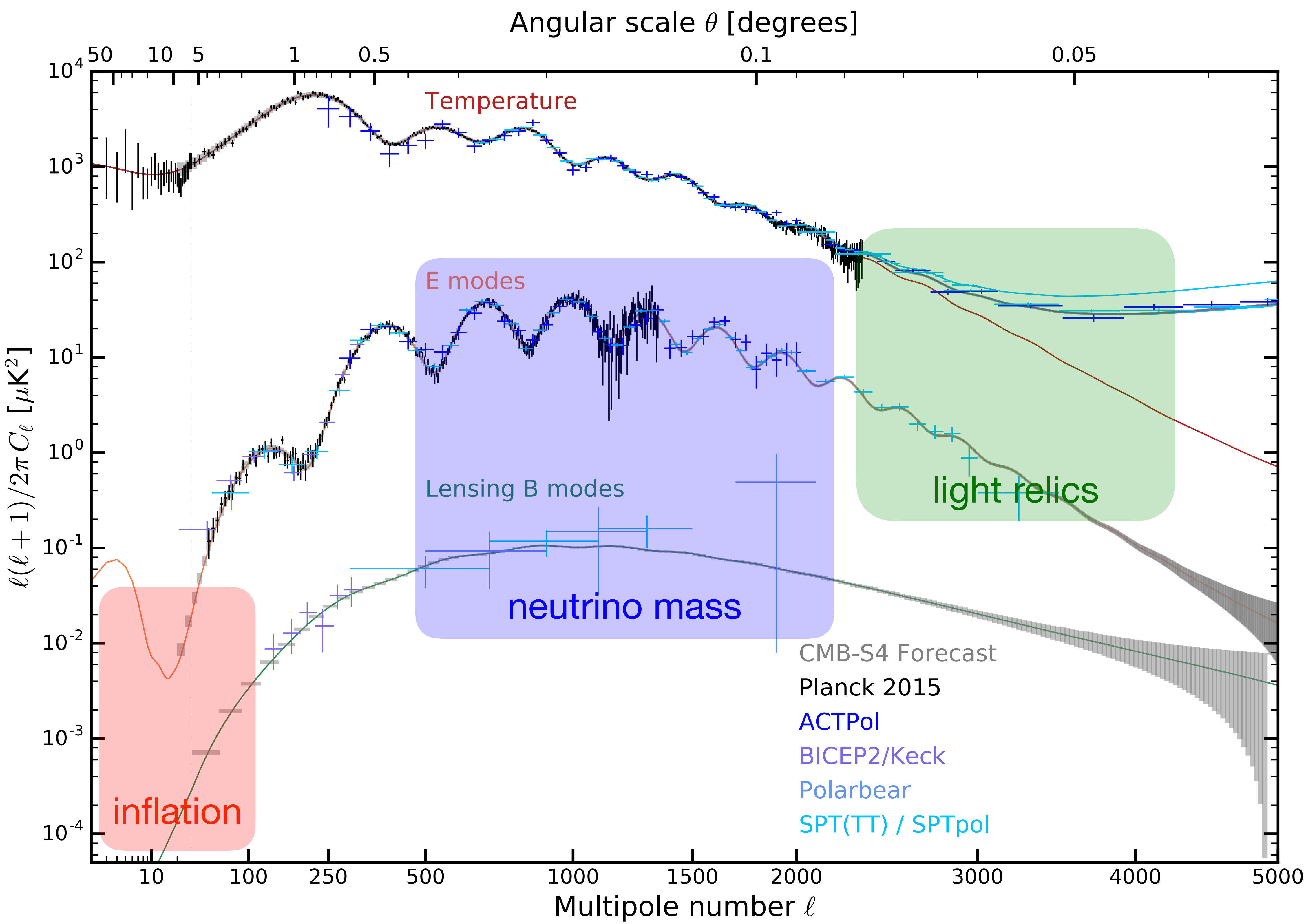
Polarization Power Spectrum



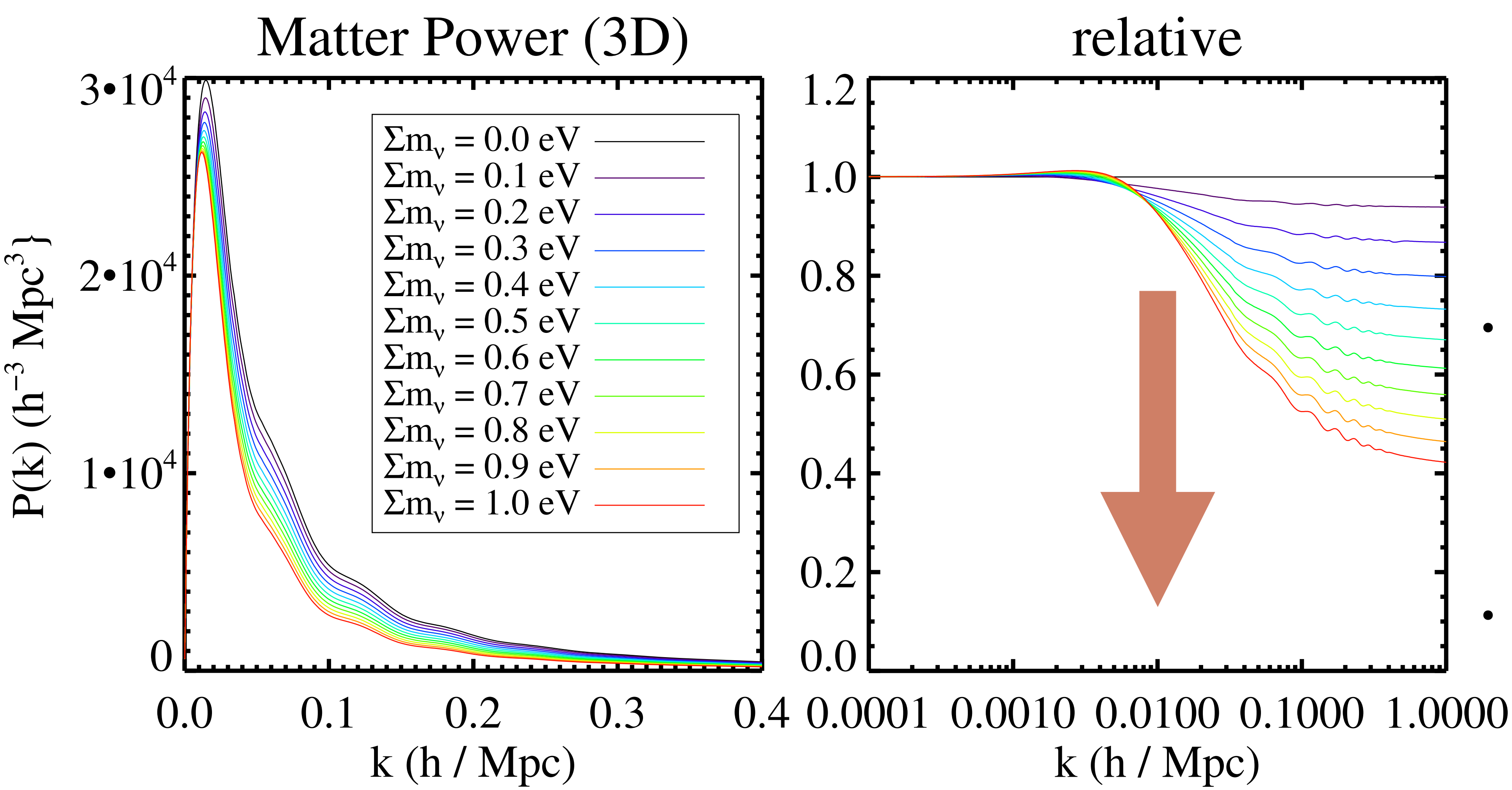
Polarization Power Spectrum



Polarization Power Spectrum



Neutrino Mass: Matter Power Spectrum

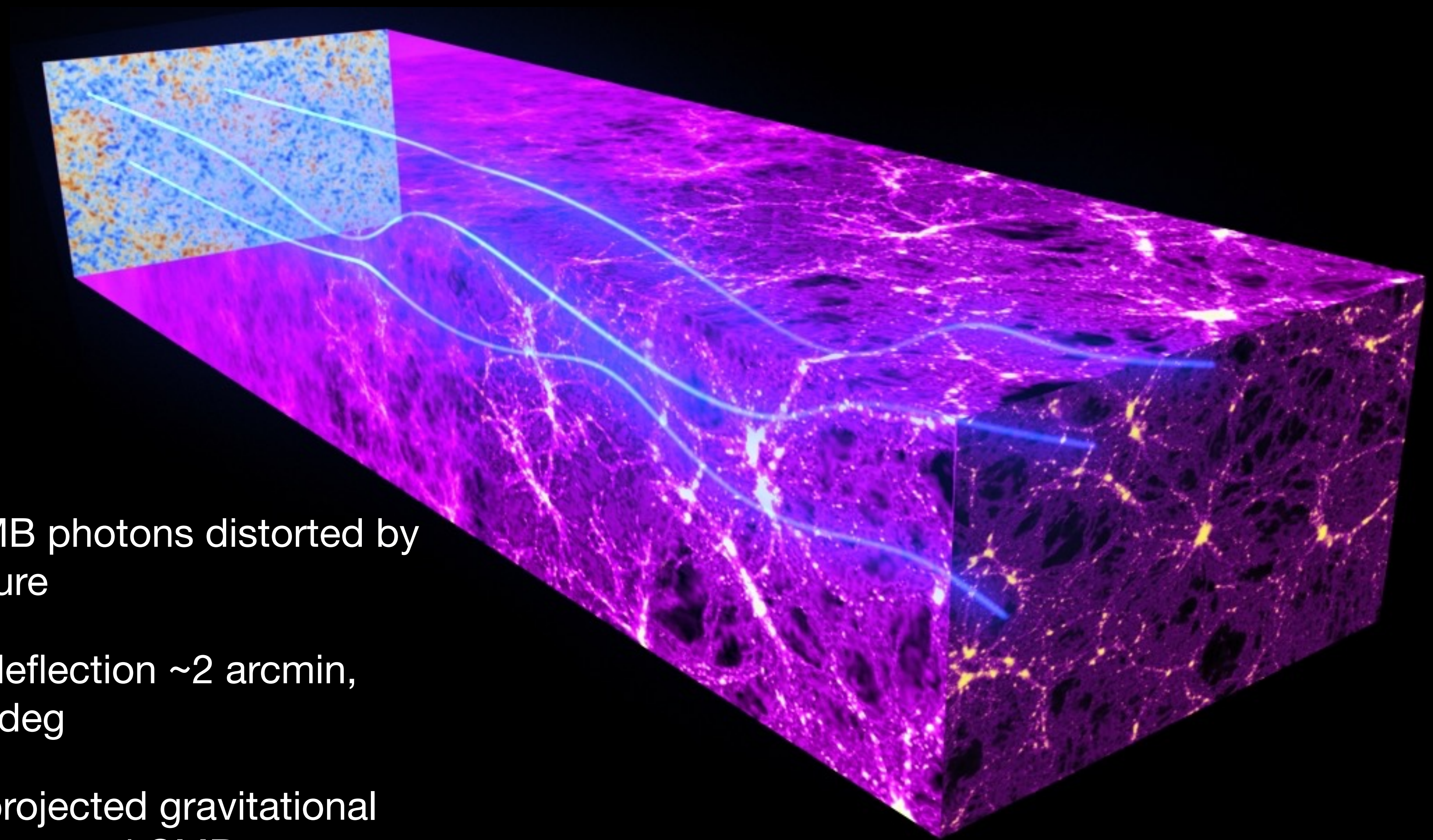


CMB-S4 science book

- ***Sum of neutrino masses affect growth of structure in universe***
- Clustering of matter suppressed at scales < 100 MPc
- ~5% suppression per 0.1eV in total mass
- ***Lower*** limit from oscillations:

oscillations depend on squared mass differences, not absolute mass scale → $\sum m_\nu > 0.06\text{eV}$

Neutrino Mass and Gravitational Lensing



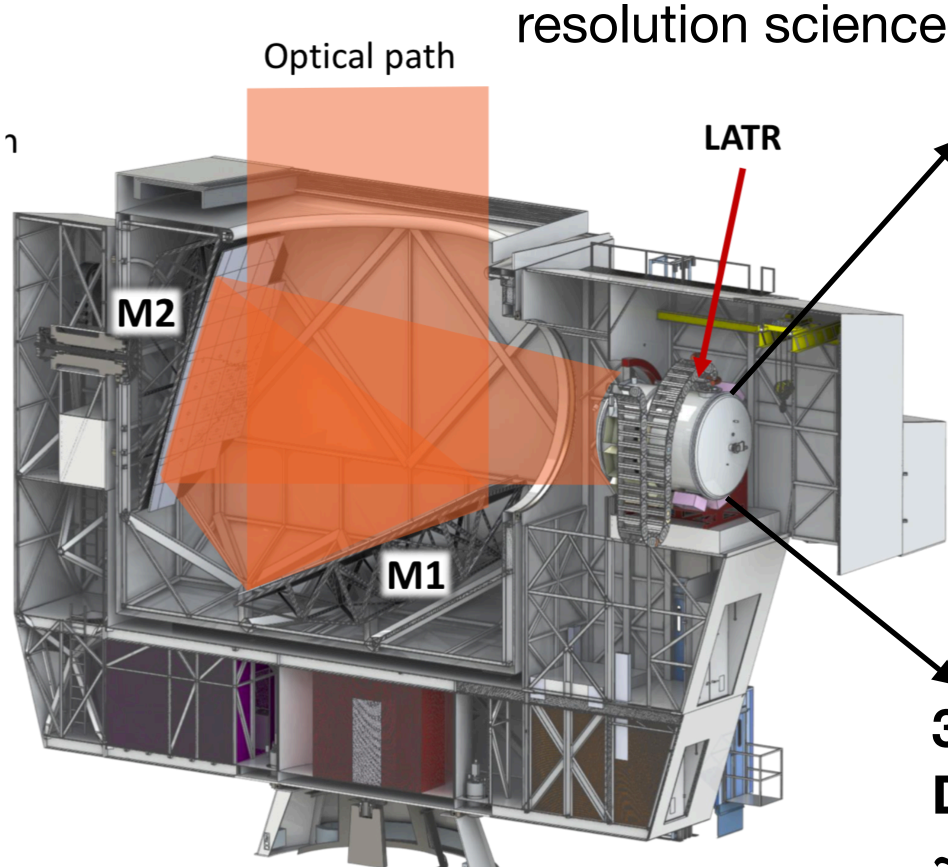
- Trajectories of CMB photons distorted by large-scale structure
- Angular scale of deflection ~2 arcmin, coherent over ~2 deg
- Reconstruct the projected gravitational potential between us and CMB

CMB probes matter power spectrum and neutrino mass

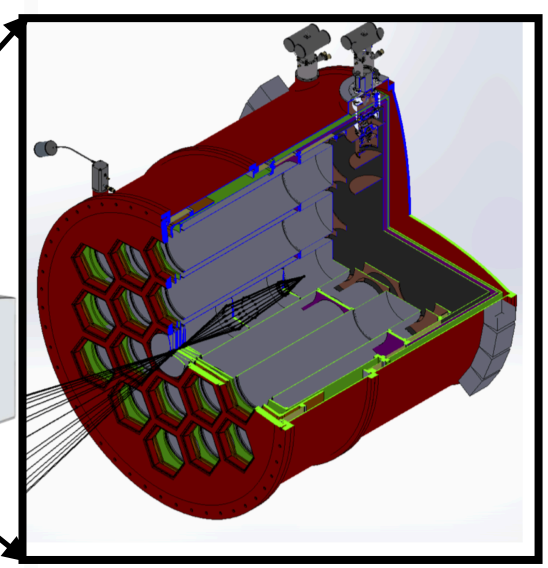
The CMB-S4 Concept

- **Concept:**
  - **400,000 detectors** split between 3x 6m-aperture, ~18x 0.5m-aperture telescopes
  - **Two sites:** Split between South Pole and Atacama in Chile
  - **Two surveys:** Inflation survey on 3-8% sky, neutrinos and cross-correlation on 40% sky

Large aperture: delensing, neutrinos, high-resolution science

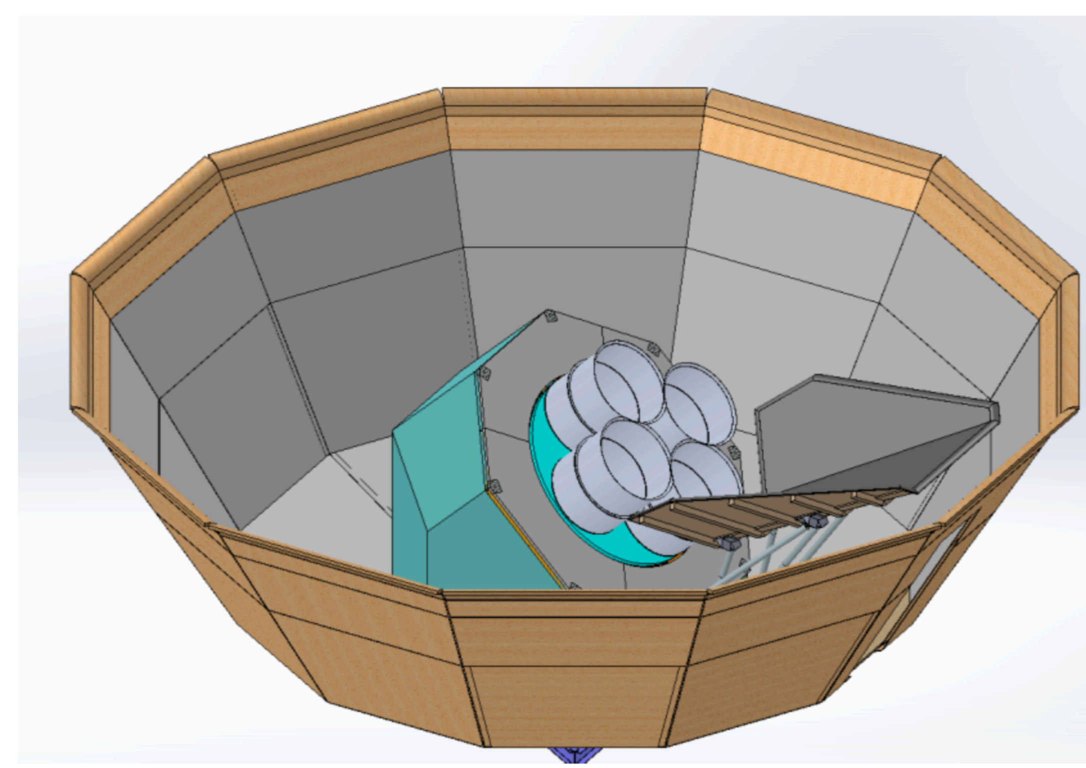


Simons Observatory LAT



3-m diameter, 9000 lbs
Dilution fridge cryostat
~100,000 TES detectors

Small aperture: inflationary B modes



BICEP Array


Questions?